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A Summary of Current Program 4/1/64

and Preliminary Report of Progress

for 4/1/63 to 3/31/64

SOIL AND WATER CONSERVATION

RESEARCH DIVISION

of the

AGRICULTURAL RESEARCH SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE

and related work of the

STATE AGRICULTURAL EXPERIMENT STATIONS

This progress report is primarily a tool for use of scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs.

The summaries of progress on USDA and cooperative research include some tentative results that have not been tested sufficiently to justify general release. Such findings, when adequately confirmed, will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting results of USDA and cooperative research issued between April 1, 1963, and March 31, 1964. Current agricultural research findings are also published in the monthly USDA publication, Agricultural Research. This progress report was compiled in the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Maryland.

UNITED STATES DEPARTMENT OF AGRICULTURE

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INTRODUCTION

In an age when man is reaching for the stars, he still has much to learn of his own planet. Although the mysteries of space fill his imagination and challenge his intellect, it is still the earth that feeds and clothes him. Soil and water resources are the substance of things hoped for. How well man understands, manipulates, and conserves them greatly determines whether his dreams of today become the realities of tomorrow.

Developing sound technology for the conservation and utilization of soil and water resources on the nation's farm and ranch lands is the prime responsibility of the Soil and Water Conservation Research Division, Agricultural Research Service, United States Department of Agriculture.

Virtually all of the nation's average annual water supply--some 4.75 billion acre-feet--falls as precipitation upon lands that are under the control of the nation's agricultural community. The condition of the land, including its vegetative cover, is a key determinant whether this water will accrue to beneficial use, be wastefully dissipated, or bring about destruction of land and property.

Agriculture faces a tremendous challenge and a great opportunity in the current and increasing competition for water. How soundly farmers manage the land and water resources under their husbandry not only affects the efficiency of agricultural enterprises, but also has a great bearing on water supplies for urban, industrial, and other uses.

Although many problems of soil and water conservation have already been solved through research and experience, those facing the nation today are of the highest possible complexity and difficulty, and as such will require even greater input of resources for solution. The problems of the future will require greater efforts and better facilities. The rapidity and permanency of solution to such problems will depend in large measure upon the effort expended.

For instance, Senate Document 97 (87th Congress, 2nd Session) sets up policies and interagency procedures for planning the comprehensive use and development of water and related land resources. Within the policies and guidelines of this Document, the Department of Agriculture, working jointly with other Federal agencies, is committed to the task of planning for the full and effective water resource development of the 18 major river basins or water resource regions by 1970 in accordance with an interdepartmentally coordinated program of comprehensive river basin planning.

Comprehensive water resources development takes into account all water uses--the interrelationship among water uses and the significant consequences that extend beyond the location of development and use. Relatively little research is underway on techniques of comprehensive planning, and the major obstacle in moving ahead with such programs is the serious dearth of physical data pertaining to our land and water resources.

The Soil and Water Conservation Research Division actively pursues many areas of soil and water research. The Division employs approximately 425 scientists, covering 17 widely varying disciplines. Its nationwide program is organized for convenience and efficiency into three main categories: (1) watershed engineering research; (2) water management research; and (3) soil management research. Information on these subjects is gathered through the activities of seven branches, organized by geographic regions. There is one Pioneering Research Laboratory--the Mineral Nutrition Laboratory--located at Beltsville, Maryland. The following seven national laboratories are incorporated into the various branches: U. S. Plant, Soil, and Nutrition Laboratory, Ithaca, New York; U. S. Sedimentation Laboratory, Oxford, Mississippi; U. S. Salinity Laboratory, Riverside, California; U. S. Water Conservation Laboratory, Tempe, Arizona; U. S. Soils Laboratory, U. S. Fertilizer Laboratory, and U. S. Hydrograph Laboratory, Beltsville, Maryland. All these, plus approximately 100 field locations, contribute to the Division's research program.

The development of plans to provide the best use, or combination of uses, of water and related land resources for the well being of all the people, both urban and rural, now and in the future, is today's challenge in the natural resources field. Sound policy and program decisions for living to the fullest within the means and limitations of our natural resources require accurate information accrued through valid research. Much of this research remains to be done.

Selected Examples of Accomplishments--1964

1. Aerial photography using color infrared film offers outstanding possibility in soil salinity work.

At Weslaco, Texas, leaf temperatures of cotton plants growing on saline soils caused by a high water table, correlate well with the soil salinity in the 0- to 5-foot profile. This points to some outstanding possibilities for remote sensing and detection of saline soils from the air, using photographic techniques and instrumentation with sensitivity in the 8- to 12-micron wavelength range. Previous photogrammetry studies using infrared film sensitive in the range to 0.9 micron explored the relation between tonal contrasts on infrared pictures and soil salinity. These earlier studies were very successful and have led to this further refinement. After thorough testing and development this technique offers unlimited potential as a survey tool in salt-affected areas throughout the world.

2. Differentials in aluminum tolerance of wheat varieties explained.

The differential aluminum tolerance of Atlas 66 and Monon wheat varieties grown in an acid soil and in nutrient is attributed to plant-induced differential pH changes around their roots. Atlas 66 was shown to be more tolerant to Al-toxic soil than the Monon variety. Root yields were the plant measurement that reflected this difference to the greatest degree. Why are these varieties different? The following hypothesis was tested; namely, the differential Al tolerance of Atlas and Monon varieties is related to the abilities of the two varieties to alter, differentially, the pH of the acid soil immediately surrounding the roots. Nutrient solution studies showed a higher concentration of Al in the roots of Al-sensitive Monon than in Al-tolerant Atlas. The higher pH of the nutrient solution surrounding Atlas could explain the lower Al accumulation in the roots on the basis of decreased Al solubility. In soil experiments also it was shown that Atlas raised the pH more than Monon. These findings show possibility of further genetic control in mineral nutrition of crops.

3. Potential for transpiration reduction by genetic control.

An investigation at Watkinsville, Georgia, measured reduction in transpiration when stomata were kept closed, in order to evaluate the potential for reducing transpiration by enzymatic control of guard cells. Stomates of several varieties of several species of plants were opened and closed by varying the carbon dioxide concentration in the surrounding air in the growth chamber. Average "observed cuticular" transpiration by corn and sorghum was 32-34 percent and 34-42 percent of total transpiration, respectively. "Observed cuticular" transpiration by cotton, tomatoes, and soybeans was somewhat higher: 66-75 percent, 64-79 percent, and 47-66 percent, respectively. Stomatal closure caused an increase in leaf temperature which varied with species. The data indicate that a decided potential exists for increasing moisture conservation through control of transpiration by incorporating those genetic factors responsible for the greater transpiration reductions found in this study.

4. Small sulfur application corrects deficiency on Oregon wheatlands.

Studies conducted near Pendleton, Oregon, indicate that a single application of sulfur (applied as gypsum) will supply the sulfur needs of dryland winter wheat grown in a wheat-pea rotation for several years. On field plots fertilized with sulfur in 1959, beneficial effects have been noted in each of three wheat crops. Where 15 or more pounds of sulfur per acre had been applied in 1959, the 1963 crop yielded 13 bushels per acre more wheat than where no sulfur had been applied. These results clearly indicate that under the dryland conditions of eastern Oregon a single application of 15 pounds of sulfur per acre will supply the sulfur needs of at least three winter wheat crops.

5. Development of an automatic grade control system for drainage machines.

At Columbus, Ohio, depth control of drainage machinery has been achieved with an automatic grade control mechanism that uses a simple fluid-dampened pendulum for maintaining the machine beam at a constant slope regardless of ground surface irregularities the machine passes over. Changes in the slope of the drain machine are sensed by electrical micro-switches which actuate solenoid valves in the hydraulic control system.

The automatic grade control was developed for the floating-beam-type mole plow used to install plastic-lined mole drains because high operating speeds limited the effectiveness of manual control. It was also adapted for use on a modified wheel-type trencher that uses a shoe thereby eliminating the need for visual sight bars.

The pendulum type of automatic grade control has given uniform and accurate drain gradients with both types of drainage machines under widely differing soil conditions and surface configurations. In operation, the machine equipped with automatic grade control is placed at the proper outlet depth, the pendulum scale set to the desired drain gradient and installation begun, thus greatly increasing the efficiency of subsurface drain installation.

6. Glass fiber and asphalt protect newly graded waterways.

Glass fiber channel liners stabilized with asphalt provide considerable protection against water erosion to newly graded waterways. Tests at the Stillwater, Oklahoma, Outdoor Hydraulic Laboratory on a newly graded 6-percent slope waterway in a sandy clay soil showed that the liner protected against erosion damage from flows up to 2.1 cubic feet per second. This amount of flow frequently occurs and causes considerable damage to new waterways. These liners will not protect waterways against high flow, however. Much costly hand repair work to waterways used for terrace outlets or the conveyance of storm runoff from highway ditches can be eliminated by the use of liners which provide temporary protection until a permanent grass mat can be established.

7. Proper timing of limited amounts of irrigation results in much greater water-use efficiency.

Limited irrigation of grain sorghum at Bushland, Texas, resulted in high yields and more efficient use of water when the water was applied during fruiting. Maximum water-use efficiency of 540 to 620 pounds of grain per acre-inch of water applied was obtained from a 4-inch irrigation at milk stage of growth. Water applied at earlier stages of plant development was used less efficiently. Irrigating for near maximum yields (7,600 pounds per acre) lowered irrigation water-use efficiency somewhat to about 300 pounds of grain per acre-inch. Results indicate that limited irrigation in relation to critical stages of plant development offers opportunity for decreasing irrigation water requirements and using limited irrigation water supplies

more efficiently. These principles of irrigation management for optimizing the efficiency of irrigation water use are of utmost importance in agricultural areas where water tables are declining or competition for limited water supplies for municipal and industrial use is increasing.

8. Corn after sugar beets shows zinc deficiency.

A field experiment conducted near Prosser, Washington, showed that sugar beets grown for three years severely affected the zinc nutrition of a subsequent corn crop. Corn following sugar beets showed severe zinc deficiency symptoms where no zinc fertilizer had been applied. Corn following three years of sorghum with or without zinc fertilizer made good growth, as did that following sugar beets where zinc had been applied. Analysis of the sugar beet and sorghum crops indicated no differential zinc removal by the two crops during the three-year precropping period. Additional work is underway to elucidate the nature of the effect.

9. Wide variations found in the drainage requirements of crop varieties and species.

Studies at Raleigh, North Carolina show that drainage requirements of crops vary widely between species, and even between varieties within species. Yields of fescue grass were similar with water tables of 8 to 29 inches, but yields of millet and corn increased as the depth to water table was increased from 6 to 30 inches. The Lee and Ogden varieties of soybeans yielded best with water tables at 6 and 18 inches, respectively. Kidney beans and snap beans both produced maximum yields at water-table depths of 6, 12, and 24 inches in sandy loam, fine sandy loam, and silt loam, respectively, indicating an interaction influence between soil properties and water table for these crops. Such data on the drainage requirements of crops, together with data on soil physical properties and rainfall, are essential in the design of drainage systems.

10. Water yield maps prepared for interior Northwest conditions.

At Moscow, Idaho maps at a scale of 1:250,000 have been constructed which show annual water yield for eastern Washington, eastern Oregon, northeastern Nevada, most of Idaho and Utah, and western Wyoming. Isohyetal lines of annual water yield were drawn by using existing stream gaging records and adjusting for mean watershed elevation, aspect, and latitude. These maps provide operations engineers and hydrologists information in enough detail to greatly improve accuracy in estimating annual water yield from ungaged watersheds subject to assistance under PL 566 (drainage areas less than 400 square miles). Most detailed maps previously available were at a 1:1,500,000 scale.

11. Conservation practices substantially reduce sediment yield.

Sediment yield from agricultural areas in the Blacklands of Texas can be reduced 88 percent by the application of a conservation program. An analysis of runoff and sediment concentration measurements from a 176-acre, non-conservation farmed watershed and a 132-acre, conservation farmed watershed showed sediment concentration to be a function of runoff rate. Mathematical expressions relating sediment concentration to runoff rate were developed for the two conditions. These relationships were applied to a 23-year runoff record to provide the determination of sediment yield reduction. The data and prediction method will provide useful tools for estimating the benefits of a conservation program applied to the Blacklands of Texas.

12. Selenium deficiency in chicks corrected by controlled selenium application to soils.

Selenium taken up from the soil and contained in alfalfa is an effective dietary source of this element for the protection of animals from the selenium deficiency diseases. In an experiment conducted in cooperation with the Cornell University Animal Husbandry Dept., workers at the U. S. Plant, Soil, and Nutrition Laboratory grew alfalfa in the greenhouse under controlled conditions of Se supply in the soil. This alfalfa was then fed to chicks in an experiment where the value of the Se taken up from the soil by alfalfa could be compared with that of equal amounts of Se added to the diet as inorganic salts of Se. The Se contained in the alfalfa proved to be essentially as effective in the prevention of exudative diathesis, a selenium deficiency disease, in chicks as was the inorganic Se. This finding means that the extensive experimental results on the prevention of Se-responsive diseases in livestock, obtained by techniques involving dietary additions or injections of inorganic Se to animals, can be applied with confidence to field situations where Se contained in plants is the principal source of this element for animals. These results also indicate that the use of selenized fertilizers for the prevention of selenium deficiencies in animals has promise, providing techniques that offer insurance against the toxic effects of excessively high levels of Se can be developed.

13. Improved method for evaluating quality of irrigation water.

An important new index of the tendency of calcium carbonate to precipitate from irrigation waters of various composition has been developed at the U. S. Salinity Laboratory at Riverside, California. The index (designated pH_c) is readily calculated from standard water analyses and graphs which have been prepared. Irrigation waters having pH_c values of less than about 8.3 tend to precipitate calcium carbonate whereas waters having values greater than about 8.3 tend to dissolve calcium carbonate. With waters which tend to precipitate calcium carbonate (pH_c below 8.3), the salt burden of the irrigation system is decreased, but the ratio of sodium to calcium plus magnesium of the soil solution and the soil exchange complex is

increased. As a consequence, sodium-affected soils are not improved and soils not so affected may become affected. Sodium-affected soils are difficult to reclaim by leaching, to irrigate and to cultivate.

14. Serious subsidence of Everglades soil in Florida.

The 5-year periodic soil resurvey made by the Fort Lauderdale Project in 1963 indicated that serious subsidence was continuing. The average rate of subsidence since 1912 has been 0.096 ft. per year. Resulting changes in topography over the vast area of the Everglades have a tremendous effect on water yield, rates of runoff, soil moisture storage, and other watershed characteristics that affect both agricultural and urban developments in south Florida. The subsidence studies point out that although it may be impractical to stop organic soil losses completely, there are several steps that may be taken to extend the life of such soil, such as: (1) providing for adequate water control facilities to keep water table as high as crops will permit, and (2) placing drained organic land in productive use as soon as possible.

Examples of Research at the State Agricultural Experiment Stations

1. Irrigation facilities.

A concrete lined irrigation ditch with metal outlet tubes was designed at the Oklahoma Agricultural Experiment Station so that water flow into a series of furrows could be accurately controlled. When the ditch flowed full of water, the discharge into the furrows was great enough for the water to reach the end of the field in a minimum of time without causing excessive soil washing. As soon as the water reached the end of the furrows, the water level was lowered in the ditch thereby reducing the flow into the furrows. This reduced rate was approximately equal to the intake rate of the soil so that a minimum of water was lost at the lower end of the field. When the irrigation was completed, the water level was again lowered in the ditch so that discharge into the furrows was stopped.

A water distribution system designed as indicated will not only reduce labor needs, but also save water. Labor requirements may be one half as much as for the ordinary irrigation system. Water will be saved since a minimum of down slope runoff will occur. Such a system also may be automated to permit further reduction in labor costs.

2. Drainage facilities.

Irrigation and soil science researchers of the University of California at Los Angeles are studying the use of glass fiber filters for drain tiles. Field tests confirmed laboratory tests indicating that glass fiber filtering materials can be used to satisfactorily replace the sand filters which have

been standard practice in draintile installations. It was observed that the glass fiber filters generally filtered out more of the fine soil particles than did the sand filters. Further studies are needed to determine how long the glass fiber will retain its effectiveness as a filter.

3. Mechanisms of soil structure.

Workers from states of the Western region, with representatives from ARS, cooperate in a regional study on the nature and mechanism of soil structure. During past years the work has been concerned primarily with identification and description of forces responsible for the formation of stable structure in soil. Currently, emphasis is being given to the mechanisms of surface crust formation. This involves evaluation of mineralogy, orientation of soil particles, presence or absence of inorganic amorphous cementing agents, behavior of organic matter, and evaluation of forces inducing rearrangement of particles. Better understanding of the mechanisms of crust formation may permit management to prevent crusts on cultivated areas and induce them where desired as a water management measure.

4. The nature of soil water.

The nature, movement and availability of water and nutrient ions in soil are of obvious importance in all soil-plant relationships. Dr. P. F. Low and associates at Purdue University have shown that water in the vicinity of clay surfaces has properties different from those of normal water. The clay and other mineral surfaces induce a rearrangement of molecules in the adjacent water. The result is an ordered or quasi-crystalline water structure that is more open and possesses greater rigidity or viscosity than that of normal water. The degree of change in structure decreases with distance from the mineral surface but some change may persist for a distance of 200-300 angstroms.

The ordered structure of water near clay surfaces reduces the rate but does not prevent movement of ions and gases. The activation energy necessary to induce flow of the ordered water is higher than for normal water. The reduced water movement would reduce availability to plant roots. In summer this would be to the detriment of the plant. In winter the reverse would be true. The ordered water does not freeze at sub-zero temperatures. A pathway is provided for water flow from lower, warmer regions of the soil to roots of perennial plants. Dessication and winter injury of such plants is thus less likely to occur.

5. Fixation and release of potassium explained.

Mica, a common soil mineral, contains potassium between its layers that is unavailable to plants. Electron microscopy observations at the Wisconsin Agricultural Experiment Station show that potassium is released from all of the cleavage surfaces of the mica sheets. As mica undergoes weathering, its

apparently smooth surface becomes cracked, pitted and etched. When this occurs the top layers roll back exposing the potassium held between the sheets. This potassium then is available to plants through exchange reactions.

The weathering, in the laboratory, was induced by salts of calcium, magnesium or sodium and is similar to what would occur in agricultural soils. Electron microscope photographs showed the laboratory weathering caused changes similar to those observed on naturally weathered mica.

By addition of a solution of a potassium or ammonium salt to the weathered mica it was possible to reverse the process. These cations replaced the sodium, calcium or magnesium on the weathered mica and the surface scrolls of the mica went back together to form a smooth surface which resembled unweathered mica once more. This process is analogous to potassium and ammonium fixation in soils.

6. Roles of the host and the bacterial species in nodulation.

Although extensive studies on nodulation of leguminous plants have been conducted, the roles of the host and of the bacterial species in the initial infection and the symbotic processes are not clearly understood. Normally rhizobial species will infect only a limited range of leguminous species--members of the same cross-inoculation group. For example, R. meliloti will induce nodule development on alfalfa and sweet clover but not on the true clovers or peas.

The legume species Astragalus sinicus, Melilotus alba and Trifolium pratense were inoculated with each of the three rhizobial strains in two parallel series--the first with the rhizobia alone, the second also received a polysaccharide containing preparation obtained from the rhizobial strain specific for the individual legume in question. In the first series the legumes were nodulated only by the rhizobial strains specific for the host genera. Infections were obtained outside the established cross-inoculation groups when the legumes were exposed to the bacteria in the presence of the polysaccharide rich fraction. These results from the Department of Agronomy, Cornell University suggest that non-infective rhizobia were transformed to infective strains through the agency of the deoxyribonucleic acid of the infective strains.

Workers in this laboratory using intact plants and excised plant parts, also have demonstrated the presence of specific host-synthesized nodulation factors. Stimulation of nodulation of excised alfalfa roots was obtained with a water-soluble, low molecular weight extract from alfalfa seeds. It was suggested that an amino compound from the host is involved in nodule initiation. These studies have important implications in the development of more infective and effective legume inoculants.

AREA 1: SEDIMENTATION PROCESSES IN RELATION TO WATERSHED DEVELOPMENT AND PROTECTION

Problem. Most sediment problems are associated with the unwanted deposition of eroded material in reservoirs, harbors, stream channels, streets and highways, or on floodplain lands. In addition to these deposition problems, sediment in streams damages fish and wildlife and it must be removed from domestic and industrial water supplies. Sediment in transport, the imbalance of the sediment load in streamflow because of alterations or impoundments in channel systems, and even erosion control practices in tributary watersheds, can also create sediment problems of major proportions. In many parts of the country abatement of sediment damages is one of the primary justifications for watershed protection and development programs.

The processes of sedimentation are complex, but an understanding of these processes and the factors controlling them is essential for the development of practices and programs for solution of sediment problems. The relation between sediment load, streamflow, land use and watershed characteristics must be clarified through research. Improved criteria are also needed for computing the bedload movement of sand, gravel and other coarse debris; for predicting the rates of silting, the trap efficiency, and the distribution of sediment in floodwater detention reservoirs; and for describing the morphology of stream channel systems having beds and banks of alluvial or cohesive soil materials.

This research seeks new and improved criteria for evaluating various sedimentation processes, for identifying sediment sources, and for developing methods for sediment control and stream channel stabilization.

USDA AND COOPERATIVE PROGRAM

The Division carries on a continuing long-term program of both basic and applied studies of sedimentation processes, involving hydraulic and agricultural engineers, soil scientists, soil physicists, geologists, chemists, and botanists, for the purpose of developing and proving new information useful in the solution of various sediment and stream channel problems. Concentrated research in all aspects of sedimentation is carried out at the USDA Sedimentation Laboratory, Oxford, Mississippi, where over half of the Division's professional personnel doing sedimentation research are headquartered.

At other locations, attention can generally be given only to the most critical problem of the region. These include studies of sediment sources and yields at Danville, Vermont; Cartersville, Georgia; Columbia, Missouri; Coshocton, Ohio; Hastings, Nebraska; Newell, South Dakota; Riesel, Texas;

Chickasha, Oklahoma; Boise, Idaho; and Tucson, Arizona. Investigations of reservoir silting are underway at Newell, South Dakota; Columbia, Missouri; Chickasha, Oklahoma; and Tucson, Arizona. Sediment transport phenomena are being studied at East Aurora, New York; Chickasha, Oklahoma; and Lompoc, California, in addition to studies at the Sedimentation Laboratory. Investigations of stream problems are conducted at East Aurora, New York; Watkinsville, Georgia; Chickasha, Oklahoma; Columbia, Missouri; Hastings, Nebraska; and Lompoc, California.

All of the studies are cooperative with the respective State Agricultural Experiment Stations and, in addition, cooperation is maintained with the Illinois State Water Survey, University of Mississippi, Oklahoma State University, and the University of Oklahoma Research Institute.

A total of 31.0 professional man-years was devoted to research in this area in the reporting period. Of this number, 15.8 man-years were devoted to studies of sediment sources and yields from agricultural watersheds; 2.8 to rates and processes of reservoir silting; 2.4 to mechanics of sediment entrainment, transportation and deposition; and 10.0 to stream channel morphology and means and measures for stabilization.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are engaged in studies of the sedimentation process. These studies seek a better understanding of the scientific principles involved in sediment movement and deposition. Efforts are also being made to determine the sources and yield of sediment from watersheds.

The total research effort in sedimentation problems at the State experiment stations is 2.0 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Sediment Sources and Yields from Agricultural Watersheds

1. Sediment sources. Five years of data from 0.05-acre (1/20 acre) plots on loessial soils with slopes of 5 and 10 percent at the North Mississippi Branch Agricultural Experiment Station, near Holly Springs, Mississippi, show that soil losses were 0.5 ton/acre/year or 0.03 ton/acre-inch of runoff for poorly managed pastures and 0.2 ton/acre/year or 0.02 ton/acre-inch of runoff for improved management. Although the effects of pasture management on sediment production are large in this case, the really significant thing is that erosion rates on these pastures are quite low, unless gullying and other bare areas develop. This lends further evidence to the observation that erosion on cultivated areas, gullying, and eroding roadbanks and stream channel systems are the principal sediment sources in the general area. (SWC 1-b1)

At the North Mississippi Branch Agricultural Experiment Station, near Holly Springs, Mississippi, average 5-year soil losses from 0.25-acre corn plots were 20 tons/acre/year or 1.0 ton/acre-inch of runoff for poorly managed areas and 6 tons/acre/year or 0.03 ton/acre-inch of runoff for areas under improved management, the latter with contour tillage and high fertilization. The 5-year average soil loss for 1.5-acre watersheds in corn were 23 tons/acre/year or 1.6 tons/acre-inch of runoff from the poorly managed areas and 15 tons/acre/year or 1.2 tons/acre-inch for the well-managed area. The difference in sediment production due to management practices, in these studies, is shown to be 68 percent on the quarter-acre plots and 38 percent on the small watersheds. (SWC 1-b1)

Frequent sampling of runoff from a Grenada silt loam soil during several storm events at the North Mississippi Branch Agricultural Experiment Station, Holly Springs, Mississippi, and subsequent size analyses of the eroded materials, showed that clay particles predominated at low runoff rates, with the proportions of silt sizes increasing as the flow rate increased. The percentage of silt and clay transported was about equal at a concentration of 3,000 to 4,000 ppm. When concentrations reached 20,000 to 30,000 ppm. and greater, the percentages of silt and clay transported were almost constant at about 70 percent silt and 30 percent clay which corresponds closely with the textural composition of the Grenada silt loam soil. This indicates that the entire surface layer of the soil was being removed from the plot at these higher concentrations. (SWC 1-b1)

At Cartersville, Georgia, the 5-year study on measurement of sediment production from bare roadbanks, and on the selection and establishment of plant species for roadbanks under varied site conditions in the Piedmont Uplands was terminated. Research was reoriented toward relating erodibility to erosive processes, to measuring the effectiveness of selected plants and their degree of coverage in preventing erosion on roadbanks, and to developing proper maintenance practices for keeping selected vegetation on critical roadside areas. (SWC 1-b1)

Instrumentation for investigation of factors affecting gully growth in the Iowa and Missouri Deep Loess Hills Land Resource Area was established during the year on study sites in western Iowa, from headquarters at Columbia, Missouri. Objectives of the research include: determining the causes of gully and channel erosion in the area; developing procedures for estimating future rates of channel enlargement and gully advance, the pattern of development (gully morphology), and the quantities of sediment eroded; and developing criteria for the design of channel and gully stabilization measures and for the evaluation of off-site effects of such measures. The studies are being carried out in gullied watersheds ranging from 97 to 140 acres in size and under carefully controlled land use and land treatment practices. (SWC 1-c2)

Studies initiated at Hastings, Nebraska, on the use of contour maps and aerial photographs to determine gross erosion on a watershed are producing positive results. Deposition of 2 to 3 inches in a small native meadow watershed during the period 1939-1963 has been established. Surface runoff during this period amounted to only 6.2 inches/acre. The results imply that native vegetation in this area serves as an effective filter, removing sediments carried into the watershed by wind. Similar analyses of a 55-acre cultivated area with 5-percent slope, show an average gross erosion of 4 to 5 inches for the same 1939-1963 period. This method of determining gross changes in watershed topography with time is to receive further investigation. (SWC 1-d2)

2. Sediment yields. A laboratory model of a gauge capable of providing a continuous record of sediment concentrations in rivers and streams, based on the principles of X-ray attenuations, was successfully flume tested at the Sedimentation Laboratory, Oxford, Mississippi, using sediment concentrations between 400 and 50,000 ppm. and flow velocities up to 6 feet per second. Good correlation between the theoretically predicted gauge response and observed values was obtained. Sediment concentrations obtained by conventional point-sampling methods agreed very well with data from the X-ray attenuation gauge. Results were sufficiently promising to warrant producing a field-type unit capable of in situ operation which is planned for completion and testing in the fall of 1964. The system will consist of a measuring head suitably located and supported at the desired water depth and an onshore unit containing electronics and data storage. The gauge will provide a value of sediment concentration integrated over 15-minute intervals for concentrations ranging from 1,000 to 50,000 ppm. The concentrations will be measured to within 20 percent accuracy at 1,000 ppm., with this uncertainty decreasing at larger concentrations. The unit will be designed to operate for 7.5 days with self-contained power and self-compensation for environmental changes of temperature and natural radiation background. The X-ray attenuation components of the gauge were selected and developed by Parametrics, Inc. under a research and development contract with the Atomic Energy Commission and the specification for the system was arrived at by the contracting parties under guidance of the Subcommittee on Sedimentation, Federal Inter-Agency Committee on Water Resources. The Sedimentation Laboratory is making the necessary laboratory and field tests for evaluating performance of the instrument. (SWC 1-b1)

Data from Watersheds W-3 (non-conservation farmed) and W-5 (conservation farmed) at Rosemont, Nebraska, each in the 400-acre size category, continue to show very significant reductions in sediment yield by adhering to conservation practices. During 1963 the watershed without conservation treatments had a sediment yield of 7.47 tons/acre compared with only 0.36 ton/acre for the treated watershed. Although annual precipitation over the watersheds, 22.8 inches, was slightly below normal, the monthly distributions varied considerably from long-time conditions. For example, September had a rainfall of 9.12 inches, which was the highest recorded amount for that month since records began in 1939. Watershed W-3 had a sediment yield of 5.71 tons/acre and W-5 had 0.34 ton/acre for September which represents 76 and 94 percent, respectively, of the annual yield. (SWC 1-d2)

Detailed analyses of data acquired in the Dry Creek watershed, a tributary of Medicine Creek in south-central Nebraska, have shown a definite relation between watershed physiographic features, sediment yield, and channel shape. Geomorphic factors, such as hypsometric curves, are found to be useful tools in describing gully erosion and in the evaluation of gully development. Continued studies have confirmed preliminary indications that in the upstream direction the bottom width of an entrenched channel increases whereas the average channel width decreases, and that these valley-trenching gullies produce up to 30 percent of the total watershed sediment yield in this physiographic region. (SWC 1-d2)

At Newell, South Dakota, sediment yields were determined during 1963 for four fine-textured soil areas and two medium-textured soil areas in western South Dakota. Results continue to show lower sediment yields from the medium-textured areas which are consistent with observed lower water yields. Maximum annual sediment yields to date have been 5.8 tons/acre and 32.2 tons/acre for the medium- and fine-textured soil areas, respectively. Sufficient data are lacking to specifically identify the reasons for yield variations in each general soil group, but this identification will become possible as more information is acquired under the continuing investigations. (SWC 1-d2)

Studies of sediment yields from rangeland watersheds at Tucson, Arizona, got underway on an important scale during the year. A number of runoff-sediment sampling installations were completed the preceding year, and the number and nature of storm flows on the Walnut Gulch Experimental Watershed in 1963 were favorable to collection of suspended sediment-load samples. Approximately 400 samples were obtained, including over 150 integrated depth samples. The sampling program was aided very greatly by radar observations of small-area convectional storms approaching and occurring over the watershed, combined with radio communication between field crews and the operations center. This enabled crews to be at the right locations at the right times for maximum sampling opportunity. (SWC 1-g1)

Analyses of sediment samples from the mainstream channel on Walnut Gulch watershed at Tombstone, Arizona, to date indicate: (1) The sediment peak precedes the peak flow; (2) sand load is lower before than after the peak and appears to be more closely related to the discharge than are the finer fractions; (3) silt load drops off rapidly after the sediment load peak and the clay-silt ratio increases; (4) correlation of consecutive depth-integrated samples is very good, indicating a valid sampling technique and feasibility of reducing frequency of sampling to facilitate sampling at additional stations in the future; and (5) results from fixed samplers on the mainstream appear to agree, generally, with those from depth-integrated samplers. (SWC 1-g1)

B. Rates and Processes of Reservoir Silting

Investigations of 51 ponds and small reservoirs for water and sediment yield from rangeland watersheds were continued at Newell, South Dakota, with initial survey work approximately 20 percent completed. Resurveys to date indicate average annual storage capacity losses to sediment accumulation vary from less than 1 percent to about 6 percent. Annual sediment yields vary from less than 0.1 ton/acre to over 32 tons/acre. Trends continue to indicate lesser sediment yields and concomitant capacity losses from areas having the medium-textured soils. However, definite correlations among soil types, drainage area size, precipitation, vegetation, and topographic features must await accumulation of sufficient data. Experience shows that ponds and reservoirs can be accurately surveyed when an ice cover exists. (SWC 1-d1)

In connection with trap efficiency studies, depth-integrated sediment samples were obtained of the inflow into a stock water pond on Walnut Gulch watershed, at Tombstone, Arizona, on several occasions during the year, and samples of outflow for one major event. Automatic fixed-stage samplers installed in the previous year to sample inflows into several other reservoirs did not function satisfactorily and will be redesigned or relocated to improve the quality of records being obtained in this study. Information on trap efficiency is essential to an understanding of the rates of sediment accumulation in ponds and reservoirs being built for water resource utilization and conservation. (SWC 1-g3)

C. Mechanics of Sediment Entrainment, Transportation, and Deposition

Tests in a 100-foot recirculating flume at the Sedimentation Laboratory, Oxford, Mississippi, with sand of 0.40 mm. median diameter and water depths varying between 0.3 and 1.2 feet have provided important new knowledge of relationships of factors affecting sedimentation processes in sand bed channels along the following lines:

1. Heights of sand dunes. An empirical relation involving mean water velocity and depth was derived to express the mean heights of sand dunes for a sand of 0.40 mm. median diameter with water depths ranging between 0.3 and 1.2 feet. This knowledge of the criteria for the existence of sand dunes or antidunes which may or may not be caused by water flowing in a sand bed channel is useful in many ways. The speed of the water is affected by the type and size of these bed irregularities and the speed affects channel capacity for water discharge and the ability of the stream to transport bed material. The water speed is also important in regard to the ability of the stream to erode its banks. Knowledge of the probable depth of the dune troughs may also be one of the deciding factors in determining the design of footings for bridges and other riparian structures. Extrapolation of the findings of this study materially beyond the conditions of the tests are not yet warranted, but these findings do provide a set of relationships which will be checked out in natural streams under field conditions. (SWC 1-b3)

2. Bed friction factor. It was found for the conditions previously specified that the Darcy-Weisbach friction factor, usually designated f, was also closely related to the empirical hydraulic variable which most successfully described the heights of sand dunes. The magnitudes of the f values closely paralleled the dune heights for a given depth, except that for increasing velocities maximum f values preceded maximum dune heights, and minimum f values followed the disappearances of dunes. This knowledge helps in understanding the effects upon water velocities of the frictional resistance of the wetted perimeter of a channel, a basic consideration in sediment transport phenomena. (SWC 1-b3)

3. Bed load related to dune properties. Bed load has been defined as the load (pertaining to particles found in significant quantities in the bed) transported in a layer 2 grain diameters thick immediately above the bed. While this definition of bed load appears precise enough, there is no way to measure it. On the other hand, relations of bed material transport to dune volume, density, and migration rate, established by these studies, yield a quantity that may be called dune load and which, perhaps, may also be assumed to be that elusive thing called bed load. For the bed material and flow conditions previously described, the dune load was found to be generally less than total bed material transport and was uniquely determined by mean stream velocity. (SWC 1-b3)

4. Total bed material transport. For a dune-covered bed the total bed material transport was found to be dependent upon mean water velocity and depth of flow. When water velocities were great enough to eliminate dunes, the total bed material transport was uniquely determined by the tractive force. The order of magnitude of total bed material transport for the 0.4 mm. sand for the latter conditions was 1 pound/second/foot width at a bed shear stress of 0.15 pound/square foot and 6 pounds/second/foot width at a bed shear stress of 0.40 pound/square foot. (SWC 1-b3)

5. Bed material transport formulas. Computed values of bed material transport by use of the Meyer-Peter, Haywood, Einstein, and Schoklitsch formulas, under the range of experimental laboratory conditions imposed, varied within 100 percent of measured values. None of the formulas showed definite superiority in accuracy; thus, the Schoklitsch formula might be preferred because of its relative simplicity--at least within the range of conditions studied. (SWC 1-b3)

At Chickasha, Oklahoma, values of the Z factor required with the Modified Einstein Procedure for calculating bed load transport in flows of the Washita River, were found to vary approximately as the square of the velocity and inversely with the depth. The Z factor is an indication of the vertical distribution characteristics of sediment in channel flow. A good relationship between Z and the velocity squared divided by depth was found for two size classifications of sands, 0.0625-0.125 and 0.125-0.250 mm. in diameter. (SWC 1-e1)

D. Stream Channel Morphology and Means and Measures for Channel Stabilization

1. Channel morphology. Thorough study and analysis is continuing on stream geometry and on hydraulic characteristics of channel improvement and stabilization works installed on Buffalo Creek in western New York State under authorizations of the Flood Control Act of 1944 and subsequent amendments. It is necessary to have reasonably accurate values of stream discharge for these analyses, and since it has not been possible to measure stream flow at all of the locations where such information is needed, work is continuing on the development of procedures for estimating discharge on the basis of high water marks and stream channel characteristics. One promising method on which effort is being concentrated is based on the premise that the transverse difference in water surface at an open channel bend is related to the geometry of the bend and to the velocity head of the flow. Several equations relating superelevation to the ratio of the radius-to-width of bend have been developed, but require further refinement. (SWC 1-a1)

In the process of developing stage-discharge relations on Buffalo Creek in western New York State a mathematical analysis was made to prove or disprove the validity of the two-point method for spacing current meter measurements of stream flow. In this method the stream velocity is measured at 0.2 and 0.8 of the depth and averaged to obtain the average velocity of the vertical section. It was found in an analysis of logarithmic, exponential, and parabolic velocity distributions that available vertical velocity curves agree closely with experimental evidence, yielding accuracy within 2 percent. In another mathematical analysis using a Taylor Series expansion, the method was shown to be valid for any unspecified function having the properties of a vertical velocity curve. The analysis demonstrated that appropriate measurement points in the vertical should be close to, but always less than, one-quarter of the depth and greater than three-quarters of the depth below the water surface. When the function was specified by a power-series expansion, an approximate numerical value of 0.21 depth was derived for the upper sampling point. Thus, by rounding off to one significant figure, the two sampling points of 0.2 and 0.8 depth are obtained, which give accurate values of the mean velocity. (SWC 1-a1)

Measurements of vertical velocity distribution of streamflow in the Washita River at Chickasha, Alex, and Verdon, Oklahoma, revealed that the average of mean velocity obtained at the 0.2 and 0.8 depths agreed quite well with the mean for the total vertical. Only in a few irregular verticals was a substantial difference found. This observation is in agreement with findings in connection with studies on Buffalo Creek in New York State as reported above. (SWC 1-e1)

The previously observed trends of slowly increasing channel width and decreasing bed elevations continue in the Barber Creek channel, near Watkinsville, Georgia, in the section where streamflow is most controlled by flood detention reservoirs upstream. The purpose of these studies is to develop procedures and guides for predetermining adjustments likely to be induced by changes in water and sediment discharge characteristics associated with imposed channel modifications, dams, or other structural installations in tributary watersheds. On this stream, resistance coefficients (Manning's "n") have shown a pattern of increasing with increasing flow depths to about bankfull stage after which further depth increases result in slight decreases in flow resistance. The point at which this reversal takes place has not yet been adequately defined. Further investigations are being directed to determine this point and why the decrease in resistance occurs above it. (SWC 1-b4)

At Chickasha, Oklahoma, a comparison of contours as derived from a transit-stadia topographic survey on a 26.4-acre field with those from machine plottings (Kelsh plotter) indicated that the plotter elevations were reasonably accurate and, with one exception, within 2 feet of the actual elevations as expected when using aerial photographs taken at a height of 2,000 feet. The exception appears to have been caused by a canopy of dormant trees along one bank of the Washita River. This study indicates that the plotter method would not be reliable for determining minor channel changes from small storms or flood plain deposition but that the method probably can be used advantageously in research on unstable channels or stream reaches with rapidly eroding banks or where widely spaced conventional cross-sections might give biased results. (SWC 1-e2)

2. Stability of channels in cohesive materials. The Sedimentation Laboratory, Oxford, Mississippi, found that the stability of channels in cohesive materials can be better understood by grouping into two primary categories those factors determining the erosion resistance of the clay fraction of the soil. The first category consists of inherent properties, including: the kind and texture of the clay mineral; the amount of clay mineral; the texture of the noncohesive portion of the soil; and the fabric of the sample, including the volume-weight, the dispersion or aggregation, and the orientation of the particles which are largely a result of the historic environment. The second category comprises the concurrent environmental factors affecting erosion resistance, including the moisture content when first subjected to the erosive force, the wetted age prior to erosion, the length of time subjected to erosion, and the temperature of the eroding water. While the above classification is no claim to a complete understanding, it is a good beginning and helps define the direction of the most needed future work. (SWC 1-b4)

At Hastings, Nebraska, a comprehensive study of stream channel stability in southeastern Nebraska was initiated. Forty-five channel reaches were selected for detailed study and survey work was initiated. The investigations will eventually encompass 150 channel reaches having contributing drainage areas ranging from less than 50 to over 1,000 acres. The investigations are designed to provide research information on channel stability as pertinent to programs and activities for the development and protection of small watersheds. The Soil Conservation Service is cooperating in the field investigational phases of the study. (SWC 1-d1)

3. Plasticity index. Knowledge of the things that affect erodibility of soils, derived from studies at the Sedimentation Laboratory, Oxford, Mississippi, now permits partial evaluation of the plasticity index as a measure of the ability of stream channel peripheral materials or other bare soil surfaces to resist erosion. The plasticity index is the difference in percentage moisture contents for the well-known Atterberg tests for liquid and plastic limits. Since the tests for the liquid and plastic limits require extreme kneading and manipulation of the soil material, the results could only reflect the effects of the three basically inherent types of soil properties. Then, only insofar as the fabric of the in-place material and the prevailing environmental conditions have negligible effects, can the magnitude of the plasticity index be considered a good representation of resistance to erosion. All this is written with the knowledge that a class of field conditions does exist, if carefully sorted out, where plasticity index may be a very good indication of resistance to erosion. (SWC 1-b4)

4. Critical tractive force. The Sedimentation Laboratory classification of the pertinent factors describing cohesive properties of clay soils also clearly indicates the fact that cohesive materials do not have a single critical shear stress or tractive force at which erosion begins. The critical flow conditions for stability are dependent upon the environment of the material during and immediately before the event. The stability or rate of erosion for a given material will generally be different if in the bed of a perennial stream than if it is on the bank or is a part of the periphery of an ephemeral stream. The erodibility of bare soils anywhere differs with changing environmental conditions. (SWC 1-b4)

5. Channel stabilization. Design and construction surveys, photographs, and other records documenting previous conditions and the history of numerous channel protection structures installed since early in the 1930's on the Calleguas Creek watershed near Moorpark, California, have been acquired from Federal Records Center storage. Field reconnaissance of the watershed has been made to identify and select locations for resurvey and study of channel reaches and structure sites to determine and evaluate factors that have affected such things as stabilized channel gradients above control structures, changes in channel alignment and cross-section, and bank stability. It is expected that this research will provide new information to help forestall increasing channel control problems accompanying land use changes, especially where urbanization is rapidly taking place as in many agricultural watersheds of southern California. (SWC 1-g2)

PUBLICATIONS -- USDA AND COOPERATIVE PROGRAMS

Sediment Sources and Yields from Agricultural Watersheds

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McHenry, J. Roger. 1963. A two-probe nuclear device for determining the density of sediments. Internatl. Assoc. Sci. Hydrol. (65): 189-202.

Stream Channel Morphology and Means and Measures for Stabilization

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AREA 2: HYDROLOGY AND WATER RESOURCES RELATED TO AGRICULTURAL WATERSHEDS

Problem. An insight into the operation of the hydrologic cycle in agricultural watersheds is one of the essential segments of knowledge required for successful development, management, and utilization of the Nation's soil and water resources.

There are nearly 12,000 watersheds in the country in the size category commonly encompassed in developments under the Watershed Protection and Flood Prevention Act, the Small Reclamation Projects Act, and similar programs. About 8,300 of these watersheds need project action for development of flood prevention systems, water supply, public recreation areas, and irrigation and drainage enterprises. In addition, it will be necessary to take into account and evaluate the hydrologic performance of all these watersheds in connection with programs of comprehensive river basin planning now in progress and projected for the future.

Research-derived procedures for estimating floodflows, water yields, hydrograph shapes, base flow, and ground water accretions in relation to the use and treatment of watershed lands in the various geo-climatic regions of the country are an urgent need. Research on relations between improvement works in upstream tributaries and floodflows and water yields downstream along the principal tributaries and the main stems of major rivers is also a conspicuous need.

This research seeks new knowledge of hydrologic processes in agricultural watersheds. From it are derived prediction equations and criteria for the more efficient design of watershed programs and utilization of water resources.

USDA AND COOPERATIVE PROGRAM

The Division has a continuing long-term program involving engineers, geologists, meteorologists, soil scientists, ecologists, and statisticians in both basic and applied research on the hydrology of agricultural watersheds. The primary purpose of this research is to provide hydrologic guidelines for the formulation of an adequate system of interrelated structural developments and associated land treatment measures for the best use or combination of uses of land and water resources within upstream watersheds and the river basins of which they are tributary.

Studies of precipitation patterns as they influence the hydrologic performance of agricultural watersheds are in progress at Beltsville, Maryland; Danville, Vermont; Oxford, Mississippi; Ft. Lauderdale, Florida; Coshocton, Ohio; Chickasha, Oklahoma; Riesel and Sonora, Texas; Santa Rosa, New Mexico; Tombstone, Arizona; Lompoc and Tehachapi, California; and Boise, Idaho. Investigations as to the role of soil moisture and evapotranspiration in operation of the hydrologic cycle are pursued at Beltsville, Maryland; Danville, Vermont; Oxford, Mississippi; Ft. Lauderdale, Florida; Coshocton, Ohio; Madison, Wisconsin; Columbia, Missouri; Hastings, Nebraska; Chickasha, Oklahoma; Riesel and Sonora, Texas; Tombstone, Arizona; Lompoc, California; and Boise, Idaho. Studies of ground water accretion, movement and basin recharge are underway at Oxford, Mississippi; Ft. Lauderdale, Florida; Coshocton, Ohio; Columbia, Missouri; Chickasha, Oklahoma; Sonora, Texas; Tombstone, Arizona; Lompoc, California; and Boise, Idaho. Aquifer-streamflow relations in agricultural watersheds are being studied at Danville, Vermont; Blacksburg, Virginia; Oxford, Mississippi; Ft. Lauderdale, Florida; Coshocton, Ohio; Hastings, Nebraska; Chickasha, Oklahoma; Madison, Wisconsin; Columbia, Missouri; Riesel, Texas; Tombstone, Arizona; and Boise, Idaho. Water yields and floodflows in relation to climatic and watershed features are being investigated at Beltsville, Maryland; Danville, Vermont; Blacksburg, Virginia; Morgantown, West Virginia; Oxford, Mississippi; Watkinsville, Georgia; Ft. Lauderdale, Florida; Coshocton, Ohio; Madison, Wisconsin; Newell, South Dakota; Hastings, Nebraska; Chickasha, Oklahoma; Riesel and Sonora, Texas; Santa Rosa and Albuquerque, New Mexico; Tombstone, Arizona; Logan, Utah; Lompoc, California; and Boise and Moscow, Idaho.

All work is cooperative with the respective State Agricultural Experiment Stations. Other cooperators in these studies include State of California, Department of Water Resources; Santa Barbara County Water Agency; Central and Southern Florida Flood Control District; Oklahoma State University; University of Oklahoma Research Institute; Vermont State Water Conservation Board; Potomac Valley Soil Conservation District; Tehachapi Soil Conservation District; Wisconsin Valley Improvement Association; and a large number of individual farmers and ranchers throughout the United States.

The scientific effort directed to this area of research totals 57.0 professional man-years. Of this number, 8.3 are devoted to studies of precipitation patterns; 6.8 to soil moisture accretion and depletion; 4.2 to ground water accretion, movement and basin recharge; 6.5 to aquifer-streamflow relationships; 12.9 to water yield and water supply and quality; and 18.3 to floodflows and storm runoff.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are currently engaged in research on the varied aspects of the hydrology of agricultural watersheds. Studies are being made on the use of radar to characterize rainfall and the effect of interception of rain and snow on moisture available for plants.

Work is also underway on the effect of watershed cover on the exchange of moisture between the soil and the air. Western regional research project W-73 is concerned with this activity. The experiment stations are cooperating closely with the Weather Bureau in analyzing precipitation records for use in predicting precipitation probabilities. Regional projects NC-26, NE-35, and W-48 are concerned with analysis of climatic patterns and their relationship to agriculture.

Research is being conducted on hydrologic characteristics of ground water basins, ground water recharge in rice areas, and on the relationship between surface and subsurface hydrologic phenomena.

Improvement in forecasting both annual and seasonal water supply by more effective snow course measurements and analysis and the relationship of run-off rates and water yield to land use practices are being studied. The Southern regional research project S-53 is concerned with the factors affecting water yields from small watersheds and shallow ground aquifers.

The total research effort in hydrologic problems related to agricultural watersheds at the State experiment stations is 21.5 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Precipitation Patterns

1. Precipitation amounts. The U. S. Hydrograph Laboratory at Beltsville, Maryland, has developed a simple procedure for estimating the frequency of daily rainfall totals up to 1-inch in magnitude for the United States east of longitude 100° W. Estimates are based upon mean annual precipitation and the mean annual number of days of precipitation greater than .01 inch, parameters which are readily available over the nation. Expectancies of the more frequent small-volume rainfalls are important in evaluations of watershed protection programs, in irrigation design, in farm management, and in the classification of climate in general. (SWC 2-aD1)

Weekly observations were made of snow structure during the winter at Danville, Vermont, by digging pits through the snowpack to the ground. These observations during the period of snow accumulation showed that: the snow temperature varied from freezing at the ground surface to 25° F. at a snow depth of 10 inches; the temperature of the snow surface was always warmer than the air temperature 2 or 3 feet above the snow; the specific

gravity of snow increased with depth; and the crust and other sharply defined boundaries made the snow layers distinctly visible. The structural conditions of the snowpack during the development of the period of snowmelt changed progressively until: the range of temperature within the snowpack was only 3 to 4 degrees; the snow layers disappeared completely; and the snowpack became a mass of coarse ice crystals. Free water reached the snowmelt pan placed on the ground only when the snowpack had attained the latter condition. The beginning of runoff from snowmelt can be predicted by observing the snowpack's structural conditions. (SWC 2-a1)

In a study of precipitation characteristics affecting watershed performance in the semiarid areas of the interior Northwest, it was found that the great point-to-point variability in mountain valleys compels the use of a large number of rain gages if annual or storm precipitation is to be estimated with the precision needed for critical runoff analyses. Ninety gages would have been required to estimate total 1963 precipitation in the 93-square-mile Reynolds Creek Experimental Watershed, in southwestern Idaho, to within 0.8 inch of the true mean. Thirty gages would have estimated precipitation to within 1.4 inches and four to within 5.2 inches. Precipitation in this valley in 1963 increased with elevation at a constant rate of 5 inches per 1000 feet on both east-facing and west-facing slopes. At a given elevation, precipitation was about 6 inches greater on east-facing slopes than on downwind west-facing slopes. (SWC 2-f2)

Radar scanning of storms was started on the Walnut Gulch Experimental Watershed, Tombstone, Arizona, utilizing radar equipment salvaged from a scrapped military plane. No effort is being made to develop methods for quantitative measurement of precipitation by radar. It is expected, however, that future photo records will be especially useful for interpolating between gages and in closing isohyets extending beyond boundaries of the experimental watershed. By observing the approach and movement of small-area storms over the watershed last season, the radar was very helpful in alerting and dispatching field crews to strategic locations for runoff and sediment load measurements. (SWC 2-g1)

2. Rainfall intensity-duration. During the past 3 years at Danville, Vermont, the 30-minute rainfall intensity of 1-year frequency, expected on the basis of long-term regional records, has been exceeded 17 times and that of 100-year frequency has been exceeded twice. Since no rainfalls for durations longer than one hour have been exceeded, this may indicate that high intensity-short duration rainfall frequencies reported in the Weather Bureau's Technical Paper No. 40 should be re-examined. (SWC 2-a1)

The storm of June 5, 1963, which centered about 5 miles from the North Appalachian Experimental Watershed, Coshocton, Ohio, has provided important information about the rainfall depth-area relationships of extreme small area storms in that part of the country. A total of 4.8 inches of rain fell in the storm core in a 1-hour period, which is almost 85 percent more than the 1-hour amount to be expected once in 100 years according to the best

available information from regional-type studies. Apparently such intense local storms occur rather frequently in this general area, although no such storm has yet centered over the research watersheds at Coshocton. Information for this particular storm was obtained principally from small inexpensive tube-type gages established by farmers living in the surrounding area. Plans are being made to extend and intensify coverage by such gages in a 2- to 3-county area to better define rainfall at the eye of small area storms and depth-area relationships. (SWC 2-c1)

At Tombstone, Arizona, short-duration maximum rainfall intensities derived from immediately adjacent recording gages with varied time scales, showed a strong bias on the low side for intensities read from gage charts having a relatively small time scale. Maximum intensities derived from 24-hour cycle gage records were substantially lower for durations of less than 15 minutes than those derived from an adjacent 6-hour gage. Most existing intensity-duration-frequency data have been derived from 24-hour or weekly cycle recording gages. This would indicate the possibility of general negative bias of short duration-frequency data, and may in part explain the generally higher than expected intensities in gage networks where 24-hour or shorter cycle recording gages have been installed. (SWC 2-g1)

A time-depth-area precipitation reconnaissance study was initiated near Tehachapi, California, with the installation of 21 recording rain gages in an area about four miles square. It is known that extremely intense convective storms occur in this area, producing localized severe flood and sediment damages, but little is known of the patterns and frequencies of these occurrences. In an August 1963 storm centered just outside the network, 3.1 inches of rain were measured by an isolated gage, compared with only 0.12 inch about 5 miles south in the network. (SWC 2-g1)

A rainfall vector study at Lompoc, California, showed the horizontal direction of rainfall on a level site to be quite uniformly distributed around the compass, and relatively uniformly inclined from the horizontal; whereas on a hillside slope the horizontal direction of the rainfall was concentrated in a particular quadrant, and its inclination was materially less. This indicates a possibility of substantial influence of land slope and slope aspect on the areal distribution of precipitation within watersheds and on the erosivity of rainfall on particular sites. (SWC 2-g1)

3. Rainfall depth-area relationships. The extent to which measurements at a single gage are representative of rainfall over the surrounding area is a practical question of real significance to practicing hydrologists. Investigations of precipitation patterns have provided some interesting and significant relationships of areal to point rainfall at several locations in the Southern Great Plains region.

At Chickasha, Oklahoma, for one-hour amounts, the ratio of area to point rainfall decreased from 1.0 for zero area (a point) to 0.55 for 100 square miles and 0.27 for 1000 square miles. For six-hour rainfall the ratios were

0.61 and 0.36, respectively. The relationships were derived from an analysis of 19 storms occurring over a 183-recording-gage network covering approximately 1,100 square miles in 1962 and 1963. (SWC 2-e1)

At Riesel, Texas, the average ratio of areal to point rainfall, over a 10-square-mile area, decreased from 1.0 for zero area (a point) to 0.85 for winter rainfall and 0.67 for summer rainfall, considering all storms with at least 1.0 inch of rain at any one gage in the gage network for the 1938-1943 period. A similar study at Sonora, Texas, showed no seasonal effect for the 1961-1962 period. The ratio for a 10-square mile area at Sonora was 0.79, about midway between the Riesel winter and summer values. Ratios for maximum rainfall amounts were higher, being about 0.97 at Riesel and 0.96 at Sonora. (SWC 2-e1)

B. Soil Moisture Accretion and Depletion

1. Infiltration. Hydrologic records from small plots and watersheds in the Northeast are being analyzed in the Hydrograph Laboratory at Beltsville, Maryland, to evaluate the volume of saturation required for various soils before the rate of infiltration becomes constant. Soil porosity data are also being assembled and analyzed to estimate the volume of potential storage above the impeding strata. These two statistics, wetting volume from hydrologic analyses and storage potential from soil analyses, will be studied for possible correlation as a basis for grouping soils of the Northeast in accordance with their hydrologic potential when in a dry condition. This grouping is intended as a supplement to the current Soil Conservation Service hydrologic grouping of soils according to their infiltration capacities when in a thoroughly wetted condition. (SWC 2-aD1)

Hydrographs of infiltrometer run on 6- by 12-foot grass-covered plots on sandy-gravelly loam soils, on the Walnut Gulch Experimental Watershed, at Tombstone, Arizona, had much more gradually rising stages than brush-covered plots, and less total runoff from short duration rainfall. After an hour of applied rainfall, the infiltration rates under grass and brush cover reached approximately the same maximum values. On semiarid rangeland watersheds where the runoff-producing rainfall is practically all in high-intensity summer thunderstorms of short duration, high initial infiltration materially affects the on-site runoff. The question remains, however, as to what net effect this may have on the runoff at any substantial distance downstream. (SWC 2-g2)

Controlled experiments at Tombstone, Arizona, involving careful water-budget accounting, have shown that abstractions from on-site runoff occur in the process of overland flow on semiarid rangeland watersheds. Substantial losses of water occur even before runoff reaches the channel system. Such losses, in addition to subsequent channel-loss abstractions, broaden the margin of possibility for watershed treatment that would increase forage production without loss of water for downstream use. (SWC 2-g2)

2. Soil subsidence. Another of the periodic 5-year surveys for measurement of soil subsidence in the Everglades basin was made from headquarters in Ft. Lauderdale, Florida, in June 1963. These surveys have shown an average subsidence of 0.096 ft./yr., indicating a loss of 5 ft. of soil over the 5.5-million acres of the Everglades in the 50 years since drainage began. The resulting changes in topography over such a vast area have a tremendous effect on water yields, rates of runoff, soil storage, and other watershed characteristics that affect the economics of both agricultural and urban development in south Florida. These surveys give continuing evidence of the validity of predictions made by J. C. Stephens in 1956[1/] that "with continued subsidence, by 1990 much of the present area of organic soils in the upper Everglades will probably be too shallow in depth to support a paying agriculture, and, by the turn of the century, most of the area will have subsided to the point of wide scale abandonment." In substance, the subsidence studies in the Everglades point out that although it may be impractical to stop organic soil losses completely, there are several steps that may be taken to obtain maximum benefits from these soils: 1) Provide adequate water-control facilities to keep water tables as high as crop and field requirements will permit; 2) place drained organic lands in productive use as soon as possible; and 3) intensify research designed to develop practices that can prolong the remaining life of the soils. (SWC 2-b1)

3. Vegetative cover. An evaluation of vegetation survey methods in sagebrush rangelands on the Reynolds Creek Experimental Watershed, near Boise, Idaho, demonstrated that variable plot sampling, a technique adapted from a widely used forest inventory procedure, is a fast and efficient means of estimating ground coverage of shrubby vegetation. The method is not usable in excessively dense shrub stands, nor for vegetation other than shrubs and bunchgrasses. Unless corrected for, deviations from circular shrub outlines significantly bias estimates. Careful training of technicians is necessary if best results are to be obtained. If proper precautions are followed, this method can be applied to shrub cover surveys in any area, at a substantial cost saving. (SWC 2-f3)

Field experience on the Reynolds Creek Experimental Watershed, near Boise, Idaho, has shown that color aerial photographs are more useful for interpretation of soil and vegetation characteristics in shrub and grassland areas than in forests. Direct color transparencies have substantial advantages over color prints for interpretation purposes despite their greater difficulty of handling. (SWC 2-f3)

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C. Ground Water Accretion, Movement and Basin Recharge

1. Ground water movement. Hydrogeological investigations at Pigeon Roost Creek watershed, near Holly Springs, Mississippi, have resulted in a reasonably satisfactory understanding of geological and ground water conditions in the basin. The principal water-bearing bed was found to be a leaky artesian aquifer, the Meridian Formation, approximately 180 to 200 ft. thick, dipping to the south and west, with a permeability of 0.1763 cm./sec. and porosity of 30 percent. Ground water storage under the watershed was calculated at about 4 million acre-feet. The Formation apparently both "gives" and "takes" water along the main stream channels, dependent on the relationship of the stream bed to the piezometric water surface. Annual water loss from the basin as ground water outflow through the Meridian was computed to be approximately 3 inches, and stable piezometric gradients for several years has led to the conclusion that such losses were steady. Relatively constant ground water levels in the watershed during the past 2-year period, when rainfall was 20 percent below normal, tend to substantiate previous evidence that the vast quantity and movement of ground water underlying the study area is not readily affected by short-term variations in rainfall. (SWC 2-b4)

Logging of water wells with a single-point electric logger at Chickasha, Oklahoma, shows that this tool can be used to differentiate between productive sandstone and nonproductive shale strata and between saline and nonsaline aquifers, which are present in the local Permian Redbed shale-sandstone formations. Both the shales that are generally nonproductive and the sandstone aquifers that contain saline water readily conduct electricity, whereas the sandstone aquifers that contain fresh water do not. (SWC 2-e4)

The total ground water storage in the 1,127-square-mile study area of the Washita River watershed, at Chickasha, Oklahoma, has been estimated at 2.4 million acre-feet and the available storage as 1.2 million acre-feet. Study of the effects of land treatment practice and watershed protection measures upon this ground water reservoir is an important aspect of the watershed research program underway in this area. (SWC 2-e4)

The network of observation wells on the Reynolds Creek Experimental Watershed, Boise, Idaho, was augmented in 1963 with a seismic refraction survey and an increase in the number of electrical resistivity measurements. A major high-angle fault that probably plays an important role in ground water flow to Reynolds Creek was located by the seismic refraction work. Also, the thickness of sediments and alluvium was determined except for a short distance on the valley floor where the sediment thickness over the basalt bedrock exceeds the effective depth of the seismic spread used. Water level measurements were made in 15 observation wells which penetrate the basalt layers. A year's measurement of these wells shows that recharge to the water table occurs primarily from winter and spring precipitation. (SWC 2-f1)

2. Basin recharge. Runoff lost in transmission in channels of arid region ephemeral streams may be largely recoverable, aside from that consumed by riparian vegetation. Ground water observation wells along the main channel of the Walnut Gulch Experimental Watershed, near Tombstone, Arizona, have shown: (a) Underground flow in the channel bed after saturation; (b) mounding effect on the regional water table along the channels after runoff; and (c) definite raising of the regional water table after the summer flow period. (SWC 2-g3)

Mean annual direct ground water recharge by deep translocation of soil moisture on brush, grass and dry farm lands near the coast in southern California is in the order of 1 inch of water. Studies at Lompoc, California, 1957-62, showed recharge occurring in years of above normal rainfall. Based on weather records at Lompoc for the period 1914-62, average annual recharge was estimated for deep sandy soils to range from 1.3 to 1.7 inches per year, depending on the cover. The high values were for dry-farmed and grass-covered areas, and the low values were for brush cover. Corresponding estimates for moderately permeable soils were 0.4 to 0.7 inch per year and for slowly permeable soils from 0.0 to 0.3 inch per year. Mean annual rainfall in the locality is about 13 inches and varies widely from year to year. The climate is mild, Mediterranean in character, and evaporative losses are affected by moist air masses moving over the area from the ocean. It is not expected that comparable direct rainfall recharge of the ground water would occur in inland areas having similar mean annual rainfall, but hotter and drier atmosphere. (SWC 2-g3)

3. Irrigation return flow. In a continuing study of irrigation water diversions and return flow in the irrigated portions of Reynolds Creek Experimental Watershed, southwest of Boise, Idaho, measurements during the past year show that for much of the irrigation season more water is diverted from the creek than is available as inflow. This is possible because water diverted through upstream ditches finds its way back to the stream as return flow and can be rediverted into downstream ditches. Of all the water diverted during 1963, approximately 56 percent was returned to streamflow while 44 percent was retained on the land to satisfy consumptive use requirements. (SWC 2-f1)

D. Aquifer-Streamflow Relationships

1. Subsurface contributions to streamflow. The constant K in the basic ground water recession equation has been found to vary with seasons, soil types, and land use on the Sleepers River Experimental Watershed, near Danville, Vermont. Data are being analyzed from seven permanent weirs on the main stream and from 68 temporary weirs on first order and larger tributary streams to refine these relationships and to relate K to watershed physical characteristics.

Seven ground water wells and 73 piezometers within the same drainage show rapid response to precipitation. Those located near the streams reflect changes in bank storage, rising rapidly in response to precipitation and receding slowly as the bank storage is depleted. These data are being analyzed to derive the ground water portion of the runoff hydrographs.

As a result of a 14-inch deficiency in precipitation, the base flow of the 330-acre watershed at Fennimore, Wisconsin has declined from an all-time high of over 1 inch per month in April 1962 to only 0.07 inch per month in December 1963. The period of below normal precipitation began in October 1962 and continued throughout 1963. The ground was frozen hard in December and January so most of the winter's snowfall ran off in the March thaw and contributed little to soil moisture recharge. Unless there is substantial replenishment of ground water in the coming spring months, the Fennimore Station will be dry for the third time in the 25 years of record. (SWC 2-c5)

Drought conditions of 1963 also caused a depletion of ground water storage and a corresponding decrease in low-flow surface water in the Washita River and tributaries under investigation at Chickasha, Oklahoma. Ground water levels in the Washita Valley alluvium have been declining irregularly since late 1959 or early 1960, and are now 1 to 2 feet lower than during the previous dry period of 1958-59. During 1963, when the rate-of-decline increased, water levels dropped 2 to 6 feet. As a result of this depletion in storage most tributaries within the 1,127-square-mile study reach became dry during the normal low-flow periods of the year and consequently discharged no surface water to the Washita during these periods. (SWC 2-e4)

2. Channel transmission losses. Water losses from stream channels in the Pigeon Roost Creek watershed near Holly Springs, Mississippi, are now considered to be more prevalent than formerly believed. A recent review of storm runoff records has revealed numerous instances of measurable channel transmission losses between tandem gaging stations. For example, losses of 12-acre-feet per mile were observed for one channel reach, 2 miles long, during a single storm event in August 1963. This loss was equivalent to 0.06 inch of runoff from the 8.6-square-mile watershed above the head of the reach and accounted for approximately 1.6 percent of the annual runoff for this watershed. (SWC 2-b4)

Runoff and precipitation records for the experimental watershed near Hastings, Nebraska, indicate significant channel transmission losses, apparently related to extended drought periods between runoff events in this loessial soil area. The runoff from watersheds of 481, 2086, and 3490 acres during 1963 was 3.03, 2.32, and 1.38 inches, respectively, with runoff-precipitation ratios of 0.132, 0.098, and 0.059, respectively. These data add materially to a further understanding of transmission losses in this watershed. (SWC 2-d1)

Channel transmission losses of runoff on the Walnut Gulch Experimental Watershed, Tombstone, Arizona, have varied widely depending on antecedent channel moisture. This shows that sound estimating of floods and yields of runoff water for downstream use is dependent not only on knowledge of the magnitude-frequency relations of storms, but also on their probable sequence. This is an aspect of rainfall prediction that has received relatively little consideration. (SWC 2-g3)

E. Water Yield and Water Supply and Quality

1. Runoff volumes. For predicting daily runoff, a new "retention" rainfall-runoff model was formulated by expressing the rainfall stored after runoff starts in terms of a storage factor and an exponential function of rainfall in excess of that "retained" before runoff begins, based upon data from the North Mississippi Branch Agricultural Experiment Station, Holly Springs, Mississippi. Initial computer solutions indicated that up to 89 percent of the concomitant variation in computed daily runoff for a 3.01-acre pasture watershed having poor cover conditions was explained by the "retention" prediction model. The method holds promise for computing daily storm-runoff volumes from long-term rainfall and temperature records, to obtain estimates of runoff frequencies and long-term water yields. (SWC 2-b3)

At Coshocton, Ohio runoff volumes under frozen ground conditions from small single-cover watersheds, generally less than 7 acres in size, were used to predict the volume of runoff from a 76-acre mixed-cover watershed to within 3 percent for the storm of March 4, 1963. Under summer conditions, and for local intense storms, estimates utilizing similar techniques have come no closer than 63 percent of measured flow from the complex watershed for any event in the 24 years of record at the station. This is further evidence that subsurface flows from unit-source watersheds account for a considerable part of the surface flow occurring on mixed-cover watersheds in this area and emphasizes the necessity of understanding the role of the soil and geology in the hydrologic performance of watersheds. (SWC 2-c2)

An abnormal series of rainfall events between May and August, 1963, the first year of data collection on twelve 2-acre grazed watersheds, has produced some revealing information on water yield for varying grazing intensities at the Cottonwood Range Field Station, Cottonwood, South Dakota. Of the 15.3 inches of precipitation recorded at Cottonwood during 1963, 6.8 inches, or 44.5 percent, fell during three storms between May and August. Rainfall intensities up to 7.2 inches per hour for a 10-minute period were recorded during a May 30 event. Runoff-precipitation ratios varied from 0.405 for the heavily grazed area to 0.050 for the lightly grazed area for the intense rainfall on May 30. The ratio, however, reversed for a subsequent low-intensity rainfall on June 15 with 0.102 for the heavily grazed and 0.376 for the lightly grazed areas, respectively. Specific explanation for this reversal in runoff has not been established but it is expected that

completion of detailed analysis of soil samples, root densities, vegetative cover, soil moisture, surface conditions, and rainfall intensities and durations, together with additional runoff records, will provide insight into the interactions occurring. (SWC 2-d1)

Records of 6.75 years' duration on a 43.3-acre watershed at Newell, South Dakota, with medium-textured soils, show an average runoff-precipitation ratio of 0.027 based on 11.2 inches of average annual precipitation. Of the 0.3 inch of runoff, 0.13 inch is derived from snowmelt. An 8-acre hardpan-spot site in the watershed produced 85 times as much runoff during a 5-minute intensity event of 10.2 inches per hour as a nearby 2.9-acre sandy site. Runoff from the pan-spot site was 6.7 times greater than from the sandy site for the year 1963. Continuing studies are designed to provide firm information on runoff-precipitation relationships by various storm intensities and durations for the various soil types and vegetative cover conditions in western South Dakota. (SWC 2-d1)

Studies at Hastings, Nebraska, indicate a significant reduction in runoff when cultivated land is returned to native grass. Two 4-acre watersheds that were farmed in a corn-oats-wheat rotation in the period 1941-1954 were reseeded to native grasses in the fall of 1961. Average annual runoff amounted to 3.64 inches, from an average of 17.74 inches of rainfall, during the May-October season for the 13-year period the watersheds were farmed, but has averaged only 1.25 inches, from an average of 20.99 inches of rainfall, during the May-October season for the 2-year period since reseeding. Continuation of this study will provide further needed insight on the effect of retired lands on runoff and water yield. (SWC 2-d1)

2. Water supply. The length of period without any runoff is a critical factor in the design of small ponds for water supplies. The effects of climate upon the amount of water that may be available as runoff from agricultural watersheds has been forceably called to attention during 1962 and 1963 through findings at the Blacklands Experimental Watershed, Riesel, Texas. By December 31, 1963 a watershed of 132 acres had undergone a 565-day period with no runoff and the no-flow period continued into 1964. The previous most severe deficiency occurred in 1955-1956 with only 0.03-inch runoff in a 516-day period. In the Blacklands area where nearly all water for livestock is obtained from ponds, the need continues for research-derived procedures for predicting dependable water supplies from upstream areas and the effects of land use and management practices upon these water supplies. (SWC 2-e4)

At Moscow, Idaho, maps at a scale of 1:250,000 have been constructed which show annual water yield for eastern Washington, eastern Oregon, northeastern Nevada, most of Idaho and Utah, and western Wyoming. Isohyetal lines of annual water yield were drawn by using existing stream gaging records and adjusting for mean watershed elevation, aspect, and latitude. These maps

provide information in enough detail to greatly improve accuracy in estimating annual water yield from ungaged watersheds in this area. Most detailed maps previously available were at a 1:1,500,000 scale. (SWC 2-f4)

The relation of size of drainage area to yields of runoff from semiarid rangeland appears to be controlled by channel transmission losses for drainage areas larger than a few acres. The unit-area yields of runoff measured within the Walnut Gulch Experimental Watershed, Tombstone, Arizona, generally vary according to some negative exponential of the size of drainage area, but the runoff from fractional-acre plots has departed sharply upward from the general form. Isolation and evaluation of factors affecting the runoff supply to the watershed channel system will require an understanding of hydrologic processes on plots and small watersheds ranging in the order of from 100 square feet to a few acres in size. (SWC 2-g3)

F. Floodflows and Storm Runoff

1. Hydrograph synthesis. Numerical experiments conducted in the U. S. Hydrograph Laboratory, Beltsville, Maryland, have provided benchmarks for decisions in the selection of parameters for generating inflow hydrographs and for routing flood flows through channel storage. A series of computations for Hurricane Creek, Arkansas, was designed to portray trends in hydrograph shape induced by variations in assumptions in such matters as the runoff curve number, the time to peak for the unit hydrograph, travel time for various reaches, etc., commonly used in synthesizing hydrographs. Validity of assumptions was judged by comparison of derived hydrographs with hydrographs observed at two tandem streamflow measurement stations. In practice, such verification is sought prior to using the technique for evaluations or design of watershed protection programs. The trends documented in this experiment serve as guides to the operations hydrologist in adjusting his initial assumptions for a more rapid convergence to the hydrograph facsimile. (SWC 2-aD1)

Analyses in the U. S. Hydrograph Laboratory at Beltsville, Maryland, demonstrated that the storage-flow relationships on the rising side of the hydrograph constitute a family of loop curves with a common recession rather than a single, fixed loop curve as generally assumed. This was also verified for overland flow, through analyses of sprinkled plot hydrographs. Testing under the controlled conditions of sprinkled plots revealed that the loop curve can be expressed as a function of rainfall intensity and the recession constant, believed to be associable with plot characteristics. A technique is needed for proportioning rainfall excess to storage or to flow in order to obtain a source-area runoff hydrograph closely allied with the storm pattern and with characteristics of the watershed. Plans are to continue analyses for closer definition of the family of loop storage indication curves on watersheds and for the correlation of the recession constant with watershed parameters. (SWC 2-aD1)

At Chickasha, Oklahoma, the unit hydrographs for six gaged tributaries of the Washita River, ranging in size from 138 to 319 square miles, have been defined in terms of a single equation in two parts combining the gamma distribution with a recession equation. Constants in these equations have been related to the time to peak, peak runoff rate, and volume of runoff. Application of the equations to ungaged tributaries is made possible by relationships of time to peak and peak runoff rate to physical characteristics of the watersheds. The basic objective of this unit hydrograph study is to characterize the flow regime of the Washita River prior to development of upstream flood abatement programs for comparison with flow regimes after treatments are installed in tributary areas. (SWC 2-e3)

At Chickasha, Oklahoma, loop ratings were successfully programmed for computer processing by the formula, $Q_u = Q_s\ (1.0 + UR)^V$ where Q_u is the actual flow rate in cubic feet per second, Q_s the steady flow rate in cubic feet per second, R the rate of change of stage in feet per hour, and U and v are empirical constants. For all gaging stations larger than 8 square miles in the Washita River Basin the value of v was found to be 0.3 while the value of U varied from 0.1 for 10-square-mile watersheds to 0.3 for 400-square-mile areas. (SWC 2-e3)

2. Flood routing. At the Hydrograph Laboratory, Beltsville, Maryland, a technique was developed for estimating flood routing coefficients directly from the exponent of the stream cross-section rating function. In this procedure, at any given instant, the upper end area of reach storage is derived as the cross-sectional area of inflow and the lower end area is derived as the cross-sectional area of outflow. Storage is computed for a given status of inflow and outflow, as the product of reach length and the average end-area of storage. The routing coefficient is derived from the rate versus cross-sectional area relationship of inflow and is directly applicable in the Muskingum equation for flood routing. (SWC 2-aD1)

A considerable effort has been made at Danville, Vermont, to compute Manning's "n" values from accurately measured properties of channels. An accurate determination was made at several cross sections of the cross-sectional area and the wetted perimeter by taking into account all boulders and rocks in the stream. Field measurements of a boulder stream channel at various stages were very tedious and difficult. It was found that as the flow increases at a section, the "n" value decreases, reaching a minimum at a stage nearly bankfull, and then increases slowly. These findings are opposite to those included in this report under Area 1D-1 for Barber Creek, a sand bed channel in Georgia, where "n" values increased with increasing depth to an intermediate point near bankfull stage and then began to decrease with further increases in depth. Obviously, further studies of friction factors in streamflow are needed. (SWC 2-a3)

3. Rates of discharge. Flood flow observations on the mixed-cover watersheds up to 4,580 acres in size at the North Appalachian Experimental Watershed, Coshocton, Ohio, showed that maximum flood volumes for a 12-hour period in March were among the largest on record. Two inches of rain falling on snow-covered frozen ground caused slightly more than 2 inches of flood runoff on March 4, 1963. Although flood peak rates in this winter storm were only one-half to one-tenth those of previously recorded summer peak values, severe flooding was experienced in downstream areas because of the large area of the storm and the large volume of runoff. (SWC 2-c3)

Interpretations of available data at Fort Lauderdale, Florida, have shown that the Cypress Creek formula, Q=CM 5/6—where Q is the peak average 24-hour runoff rate in c.f.s., C a runoff coefficient, and M the size of drainage area in square miles—gives reliable estimates of maximum average 24-hour runoff for agricultural watersheds in the 15- to 100-square-mile category in the Gulf Coast, Atlantic Coast, and Southern Florida flatwoods where rainfall excess can be determined for the 24-hour storm. Values of the coefficient C can be obtained with reasonably accuracy from the relationship $C=16.39 + 14.75\ R_e$, where R_e is rainfall excess in inches. Relating rainfall excess to probable recurrence periods requires judgement and knowledge of the capacity for infiltration of the soils involved. A useful estimate is obtained in many instances, however, by subtracting approximately 3 inches from the predicted maximum 24-hour storm rainfall. (SWC 2-b1)

The peak rate of unit hydrographs from a 132-acre watershed at the Blacklands Experimental Watershed, Riesel, Texas, has been reduced by 50 percent as a result of terracing, land use conversions, and improved rotations. The peak runoff rates from major storm events after conservation treatment, however, are larger than those predicted by the post-treatment unit hydrograph. The pretreatment hydrograph actually provides a better estimate. One explanation is the lack of flow in the stream channel for the storms used in derivation of the after-treatment unit hydrographs, whereas for the larger events flow is usually present in the stream channel. (SWC 2-e3)

Eleven people each made wading and crane measurements on the Washita River at Chickasha, Oklahoma, to determine the precision of current water measurements of discharge. The mean of all measurements was 100.4 c.f.s. Deviation from the mean varied from minus 6 percent to plus 10 percent. All but three measurements were within 4 percent of the mean. No significant difference was found among individuals but there was a significant difference, at the 98-percent level of confidence, in results of wading procedure compared with bridge crane procedure. With one exception each crane measurement indicated a greater flow rate than its corresponding wading measurement. With the crane measurements, many of the velocity observations were made at 0.8 depth where a single 0.6 depth observation, because of the shallow depth, should have been substituted for the average of observations at the 0.2 and 0.8 depths. An attempt will be made to verify this assumption by additional testing. (SWC 2-e3)

The largest known precalibrated runoff measuring structure in the country, having a design capacity of 22,500 c.f.s., was constructed at the outlet of the 58-square-mile Walnut Gulch Experimental Watershed at Tombstone, Arizona. With a maximum top width of 176 feet at the entrance and depth above the invert of 17.25 feet, the structure required the pouring of 1200 cubic yards of concrete. The foundation of the flume is a cellular construction with cross-stream walls founded on conglomerate and lateral walls extending several feet to undisturbed valley fill material. The cells are filled to near grade with riverbed sand and gravel. The flume floor and sidewalls are a reinforced thin concrete slab transmitting all loads to the support walls. Site-mixed concrete utilized sand-gravel from the streambed for aggregate. The total cost was less than $2.50 per c.f.s. capacity, including a massive stilling basin required for scour protection at the flume outlet. Scale model studies made in the ARS Hydraulic Laboratory at Stillwater, Oklahoma are the basis for design and calibration of the flume. (SWC 2-g2)

G. Hydrologic Data Releases

Selected hydrologic data for 157 experimental agricultural watersheds maintained by the Division, for the years 1956-59, inclusive, were published in USDA Miscellaneous Publication 945. Hydrologic data included in the publication consisted of watershed descriptions and maps, monthly precipitation and runoff, annual maximum flows, isohyetal maps, and certain tabulations for selected runoff events. Publication of such data prior to 1956 was in three loose-leaf volumes on monthly precipitation and runoff, annual maximum flows, and selected runoff events. Publication of data subsequent to 1959 is being accelerated and is expected to become current by 1966. Hydrologists and watershed planners in Federal, State and local agencies, in basin commissions, in universities, and in private agencies and consulting firms find this source of hydrologic data of great value in connection with their work on the planning, development, and protection of our national water resources. (SWC 2)

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AREA 3: HYDRAULICS OF IRRIGATION, DRAINAGE AND WATERSHED STRUCTURES, CHANNELS AND FACILITIES

Problem. Water control structures of various types represent the largest part of the public and private cost for watershed protection and development programs. They are also essential, and expensive, features for irrigation and drainage developments. Research on the hydraulic design of water control structures will reduce the possibilities of overdesign, which increases the costs unjustifiably, or underdesign, which may result in costly failure. All items of costs not required for safe functioning of structures must be eliminated.

Development of new concepts in the geometry of spillways, drop structures, and stilling basins at pipe outlets and below overfall structures are included in this research. Other studies include development of new and improved devices for control of floating debris and vortices at the entrance to closed conduit spillways; investigations of energy losses associated with various components of water control structures, hydraulic jumps, the dynamics of overland flow and flood wave velocities and energy gradients in channels of various roughnesses; and development of improved flumes, weirs, gates, and rating sections for streamflow and water discharge measurement. The hydraulic properties of various grasses and other vegetation in water channels are also determined and the effectiveness of mats and mulching materials as an aid in the establishment of grass-lined channels and waterways are tested and evaluated.

It is not possible or desirable to model the many hundreds of agriculture-related water control structures built each year, as is the usual custom with the larger dam and spillways on the main river systems. This research, instead, seeks to establish principles and develop dimensionless designs which can be adapted to various site situations and size requirements on individual farms and ranches and in upstream watersheds.

USDA AND COOPERATIVE PROGRAM

The Division has a continuing long-term program in which hydraulic and agricultural engineers are engaged in both basic and applied research on the hydraulic performance and engineering design of water control structures and channels. The studies are oriented primarily to provide information relating to the types of structures and channels involved in group irrigation, drainage and watershed protection activities. The investigations are conducted by means of: mathematical analysis of basic physical principles; studies of models ranging in size from miniatures tested in laboratory flumes to full-size replicas tested in outdoor laboratories; and scientific observations of existing structures and channels in the field.

The research is conducted primarily at the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota; the Outdoor Hydraulic Laboratory, Stillwater, Oklahoma; and in the Walnut Gulch Experimental Watershed, from headquarters at Tucson, Arizona. Developmental work for more efficient spillways and other water control structures is carried on by means of coordinated studies at both the St. Anthony Falls Hydraulic Laboratory and the Outdoor Hydraulic Laboratory, with the latter being equipped to study the performance of small, full-size pipes and structures. Investigations of overland flow and the hydraulics of vegetated channels are carried on at the Stillwater, Oklahoma location. Studies of flood wave movement in semidesert streams are emphasized at the Arizona location.

The work is cooperative with the Arizona, Minnesota, and Oklahoma State Agricultural Experiment Stations, and with the St. Anthony Falls Hydraulic Laboratory, University of Minnesota. Close working relations are also maintained with the Soil Conservation Service, Bureau of Public Roads, Illinois State Water Survey, Minnesota Highway Department, and the Oklahoma State Highway Department.

The scientific effort devoted to this area of research totals 8.0 man-years in the reporting period. Of this number 2.8 are devoted to basic studies of hydraulic phenomena; 3.7 to criteria for hydraulic design of water control structures; 0.4 to hydraulics of waterways and vegetative channels; and 1.1 to flow measurements and water metering devices.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are engaged in research on the hydraulics of irrigation, drainage, and watershed facilities. Basic studies are being made on the energy conversion mechanisms in incompressible fluid flow. Improved hydraulic design is being studied for erosion control and drainage structures.

Studies are also being made on the hydraulics of subcritical flow in small, rough channels; hydraulics of irrigation by surface flooding methods; and the effects of channel hydraulics on the runoff hydrograph. Part of the effort in Western regional research project W-65 is directed to this activity. Methods of measuring irrigation water are also being studied.

The total research effort in hydraulics at the State experiment stations is 6.9 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Basic Studies of Hydraulic Phenomena

1. Effect of crest thickness on crest loss coefficient of drop inlet spillways. A series of tests at the St. Anthony Falls Hydraulic Laboratory has established that no change results in the crest loss coefficient of a two-way drop inlet to a closed conduit spillway when the crest thickness becomes greater than a certain value. Crest thicknesses tested have ranged from 0.104D to 0.658D, where D is the pipe diameter, with inlet lengths of 1.5D, 2D, 3D and 5D, and for antivortex plate heights of 0.2D, 0.4D, 0.6D, and 0.8D above the drop inlet crest. The crest loss coefficient is largest for the thinnest crest and decreases as the thickness increases. The minimum value occurs when the crest becomes 0.5D and remains constant for greater thicknesses. This finding can be verified theoretically. The crest loss coefficient describes the energy loss that occurs between the headpool surface and the mid-height of the drop inlet. (SWC 3-c1)

2. Effect of pipe thickness on entrance loss coefficients of hood inlet spillways. At the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, studies were conducted on a re-entrant hood inlet to compare the entrance loss coefficients obtained from the air model with those obtained from the water model. Pipe wall thicknesses used were 0.00133D, 0.00267D, 0.001300D, 0.02367D and 0.03600D, where D is pipe diameter. All these pipe wall thicknesses are considered thin. The results show that the entrance loss coefficient decreases sharply as the pipe wall thickness increases. This is in agreement with the water model results. However, the magnitudes of the entrance loss coefficients determined from the air tests are less than those determined with water, varying from about 0.03 for a zero wall thickness to about 0.10 for a relative wall thickness (tp/D) of 0.04. The reason for this is unknown. Pressure coefficients obtained at the crown and invert at a distance D/2 downstream from the entrance show good agreement between models. (SWC 3-c1)

3. Effect of slope on entrance loss coefficients of hood inlet spillways. Tests at the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, on the hood inlet projecting through a sloping dam face with a level berm at the elevation of the entrance invert show that the entrance loss coefficient decreases as the pipe slope increases. Slopes tested were 0.00, 0.025, 0.05, 0.10, 0.20 and 0.40 and pipe wall thicknesses ranged between 0.00133D and 0.03600D, where D is pipe diameter. Only one series of air tests could be compared with the water tests. The agreement was excellent. (SWC 3-c1)

4. Spatially varied flow. At Stillwater, Oklahoma, the profile of a steady state, spatially varied flow in a 400-foot-long, V-shaped, bermudagrass-lined channel differed from the profile computed by the equation of motion and continuity of a spatially variable flow. Depths of flow were less than predicted at the outlet end but greater than predicted at the upper end of

the channel. Since there was no consistent difference in depth, either all high or all low, the difference cannot be assigned to change in the friction factor. These studies of spatially varied flow are continuing, with the ultimate objective of providing improved criteria for the design of diversion and similar agricultural conservation channels. (SWC 3-e1)

B. Criteria for Hydraulic Design of Water Control Structures

1. Two-way drop inlet with round bottom. A series of tests at the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, have shown that the two-way drop inlet with a round bottom must be three or more pipe diameters deep to cause the conduit to flow full and insure satisfactory performance. Previous tests have shown that the minimum satisfactory length of the drop inlet is 1.5 pipe diameters. (SWC 3-c1)

2. Crest loss coefficients for a two-way drop inlet. A single curve representing the effect of crest thickness, drop inlet length, and antivortex plate height on the crest loss coefficient in a two-way drop inlet was developed at the St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota. Experimental data obtained with the air model agreed very well with the theoretically derived curve. This excellent agreement between the theoretical predictions and the experimental results has greatly increased the confidence in the use of the air-model to study hydraulic phenomena. The development of the theoretical curve makes it possible to apply the research findings to a wide variety of combinations of structure design dimensions without additional laboratory tests. (SWC 3-c1)

3. Trash racks. At Stillwater, Oklahoma, tests of a full size drop inlet on a pipe spillway showed logs and sticks in the flow to have no effect on the capacity of the entrance during the rising stage. In the falling stage, accumulations of trash on the entrance trash rack caused a reduction in the weir coefficient from 3.0 to 2.4 for a head over the weir equal to the crest thickness. In the pipe flow range, the reduction of flow capacity for the pipe spillway was only 4 percent. (SWC 3-e2)

4. Performance of a hood inlet. The hood inlet entrance for pipe spillways has received widespread acceptance in the field of soil and water conservation engineering. Its positive priming potential has led to its extensive use on farm reservoir spillways and, in a few instances, on principal spillways for flood control detention reservoirs. Manufacturers of corrugated pipe now offer a commercially produced version of this entrance complete with an antivortex baffle. This ready availability has also tended to promote the use of the hood inlet. However, the initial good reception accorded this device has been clouded recently by doubts that have been raised in some quarters as to its effectiveness under field conditions. A series of tests were undertaken, with full size pipes, at the Outdoor Hydraulic Laboratory, Stillwater, Oklahoma, to evaluate performance of the hood inlet under field conditions with the following results:

a. Results of the full size smooth pipe tests confirmed the results of the hood inlet model studies by Blaisdell and Donnelly.[2/] This indicates that the model prediction data can be used to accurately predict the hydraulic behavior of geometrically similar prototype spillways.

b. The full size rough pipe spillways did not perform as predicted by the smooth pipe model studies in that a higher head was required to prime the rough pipe spillways than was required to prime the smooth pipe spillways. Additional model studies with a corrugated pipe model showed that this was not a fault of the hood inlet but was due to the pipe boundary condition. The hood inlet caused the entrance end to seal once the inlet was submerged, but the flow would not move down the pipe because the water would hang up at the crown of the pipe at a surface discontinuity such as a corrugation or a joint offset.

c. The weir flow equation developed from the model studies accurately predicted weir flow for all of the full size hood inlet pipe spillways.

d. The entrance loss coefficients presented by Blaisdell and Donnelly will give good entrance loss estimates for hood inlet pipe spillways.

e. The vortex activity associated with the full size hood inlet spillway without an antivortex device did not significantly affect the discharge capacity or hydraulic behavior of the spillway. This spillway was a corrugated metal pipe spillway with the pipe slope almost equal to the friction slope. This result indicates that corrugated metal pipe hood inlet spillways with the pipe slope equal to or less than the friction slope do not need a device to suppress vortex activity. However, hood inlet spillways with the conduit slope greater than the friction slope probably require antivortex devices since these spillways will have greater entrance velocities by virtue of the greater total head.

f. The pipe spillway with a hood inlet primed at a significantly lower head than the pipe spillway with a square-end inlet.

g. The Darcy-Weisbach friction factor for the 12-inch helical pipe showed no systematic variation with the Reynolds number in the flow range studied. Therefore, the average friction factor value of 0.041 is satisfactory for design purposes for 12-inch helical corrugated metal pipe.

2/ Blaisdell, Fred W., and Donnelly, Charles A., Hydraulics of Closed Conduit Spillways, Part X. The Hood Inlet. St. Anthony Falls Hydraulic Laboratory Technical Paper No. 20, Series B. April 1958.

h. The Darcy-Weisbach friction factor for the 8-inch helical corrugated metal pipe decreased slightly with increasing Reynolds number, but a value of 0.035 is satisfactory for design purposes for steep pipe spillways under normal field conditions. (SWC 3-e2)

C. Hydraulics of Waterways and Vegetated Channels

1. Vegetated waterways. At Stillwater, Oklahoma, experiments showed that encroachment of trees and brush in a grass-lined waterway through inadequate maintenance increased erosion of the bed. Soil removal rate in the center portion of the waterway was 0.97 inch of depth per hour for a tractive force of 5.8 pounds per square foot when trees were present. This was four times the soil removal rate for a similar flow in the same channel when no trees were present. Woody vegetation encroachment in the test waterway over a 10-year period reduced the effectiveness of the grass lining by shading and thinning and increased the turbulence and eroding capacity of the flow. (SWC 3-e1)

Glass fiber channel liners stabilized with asphalt provide considerable protection to newly graded waterways from erosion by flowing water. Tests at the Outdoor Hydraulic Laboratory, Stillwater, Oklahoma, on a newly graded 6-percent slope waterway in a sandy clay soil showed that the liner gave protection against erosion damage from flows up to 2.1 cubic feet per second. This amount of flow frequently occurs and causes considerable damage to new waterways. These liners will not protect waterways against high flow, however. Much costly hand repair work to waterways used for terrace outlets or the conveyance of storm runoff from highway ditches can be eliminated by the use of liners which provide temporary protection until a permanent grass mat can be established. (SWC 3-e1)

At Stillwater, Oklahoma, Mannings "n" was found to be 0.030 for an intact, asphalt-stabilized glass fiber mat channel liner. For the same channel, after some erosion had occurred and with flow beneath the liner, the "n" value ranged from 0.026 to 0.066. (SWC 3-e1)

D. Flow Measurement and Water Metering Devices

1. Big Dry Creek. Model tests, at the Outdoor Hydraulic Laboratory, Stillwater, Oklahoma, of a 1 on 5 V-notch weir placed 9 feet upstream from the entrance of a 3-barrelled culvert 10 feet high and 37 feet wide (total flow width) showed the structure to be a satisfactory flow meter for Big Dry Creek, a tributary of the Washita River near Chickasha, Oklahoma. Addition of the V-notch weir reduced the flow capacity of the culvert by 4.4 percent, a figure which was acceptable to the Oklahoma State Highway Department. The bridge was modified for flow rate measurement purposes in connection with hydrologic investigations in the Washita River Basin. (SWC 3-e1)

2. Ephemeral sandbed streams. Model studies to establish dimensions and rating curves for flumes adapted as flow-rate measurement devices in the Walnut Gulch watershed near Tombstone, Arizona, were continued at the Outdoor Hydraulic Laboratory, Stillwater, Oklahoma. The critical-depth flumes developed by the Laboratory provide a good automatic measure of the runoff from flashy, sediment-laden flows characteristic of many of the ephemeral streams of the Southwest. Even so, because of the relatively few runoff events in this part of the country and the need to obtain all possible information from these events, personal observations to augment automatic flow measurement records are very desirable. (SWC 3-e1)

PUBLICATIONS -- USDA AND COOPERATIVE PROGRAMS

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Hydraulics of Waterways and Vegetated Channels

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AREA 4: CONSERVATION OF WATER SUPPLIES FOR AGRICULTURAL USE

Problem: The increased competition agriculture is facing from industry and domestic users for a limited water supply requires the development of new sources of farm supply as well as increased efficiency in the collection, storage, conveyance, and use of existing supplies.

Irrigated agriculture currently uses about 190,000,000 acre-feet to supply an irrigation water requirement of 114,000,000 acre-feet. The difference, 76,000,000 acre-feet, is lost to the farmer largely through seepage, evaporation, use by nonbeneficial plants, and wasteful runoff during irrigation.

Falling water tables resulting from withdrawals exceeding recharge are increasing pumping costs and the danger of depleting the supply over an appreciable area.

The conversion of cropland to grazing land requires an adequate livestock water supply strategically located to preserve the newly developed pastures. This is also a critical problem on many established dryland grazing areas. Flash storms of sudden snowmelt result in wasted runoff. Systems for collection and conveyance of this water to crop areas would greatly benefit the Plains' farmer.

Many acre-feet of water are transpired by vegetation of noneconomic value. Replacement with vegetation of economic value would greatly benefit the rangeland areas.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of water conservation, utilizing agricultural and hydraulic engineers, soil physicists and chemists, and geologists. At the U. S. Water Conservation Laboratory, Tempe, Arizona, the research and development effort is directed toward the development of low cost methods for control of seepage from storage and conveyance structures; suppression of evaporation from soil, plant, and water surfaces; water harvest procedures, materials, and storage structures; water measurement; and ground water recharge. In Nevada, work is concerned with seepage control using bentonites, water salvage from phreatophytes, and the establishment of replacement vegetation of economic value. Ground water recharge studies are underway in the Central Valley of California and the High Plains of Texas. Development studies of seepage control, water control devices, and precipitation collection and storage by use of artificial rubber, plastics, and asphalt-impregnated fabrics are underway in Utah. Water-measuring devices and control structures are under

study and development in Colorado and Idaho. Farm pond size in relation to water yield and the magnitude of losses and the development of dug ponds to tap shallow aquifers are under study in Georgia.

The field station work is in cooperation with the state experiment stations or other state agencies in the states in which the work is located. A PL-480 research project on methods for desilting runoff water for ground water recharge is conducted by the Israel Institute of Technology, Technion, Israel. The scientific and engineering effort in this area totals 28.0 professional man-years per year. Of this total 9.9 are devoted to control of seepage and suppression of evaporation from surfaces; 7.9 to development of farm water supplies, related equipment, and water measurement; 9.0 to methods, practices, and devices for ground water recharge (including 1.4 for the PL-480 study); and 1.2 to reclaiming and reuse of wasted or contaminated waters.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are conducting research on the conservation of water supplies. These studies are seeking to make better use of available water supplies through reuse and by reducing unnecessary seepage and evaporation losses.

The total research effort in conservation of water supplies at the State experiment stations is 7.1 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Control of Seepage and Suppression of Evaporation from Surfaces

1. Seepage. Loss of water through seepage from storage and conveyance structures represents a real loss to the immediate farmer, even though the seepage water may move to the ground water for future use by other farmers who pump from the aquifer. If seepage contributes to a high water table, it represents a double loss to the immediate farmer.

Two stock ponds were successfully sealed with sodium salts by the U. S. Water Conservation Laboratory to confirm previous laboratory work on controlled reduction of soil porosity without complete destruction of soil structure. Sodium carbonate and tetrasodium pyrophosphate were spread by hand and disked into the soil at rates which laboratory findings had indicated would partially but not completely break down the soil structure. The soil was not compacted after disking. Seepage from both ponds was reduced from a pretreatment rate of about 5 inches per day to a posttreatment rate of about 0.15 inch per day.

The Tempe falling head seepage meter developed at the U. S. Water Conservation Laboratory was shown to be suitable for routine field use during a cooperative field study in Utah with the Soil Conservation Service. Instrumentation has been modified to simplify operation and an instruction manual for field use has been prepared. Numerous measurements in canals with varying bottom material have shown that measurements are not significantly affected by time or by the depth of inserting the seepage cup into the canal bed material.

The quantitative influence of local conditions on seepage from canals has been determined in a study at the U. S. Water Conservation Laboratory. An electrical resistance network analog was used to investigate the effect of canal shape, water depth in the canal, depth to water table, and soil stratification. Although absolute seepage losses increase from triangular to trapezoidal to rectangular canal cross sections, the carrying capacity increases at a higher rate so that percent of flow lost to seepage is less for rectangular canals than for trapezoidal or triangular canals. On the same basis, the percentage of water lost decreases as depth of water in a canal increases. Seepage increases as depth to water table increases but, for standard trapezoidal cross sections, seepage essentially reaches the maximum value when water table depth exceeds six canal bottom widths. The effect of unsaturated flow on seepage from canals has been analyzed in electrical analog studies and an equation developed to describe the effect of unsaturated flow for shallow water table conditions. Dimensionless graphs were developed to describe the flow when water tables are relatively deep.

Maximum movement of cracks in concrete farm ditch linings was found to be about 0.03 inch in field studies conducted by the U. S. Water Conservation Laboratory. The cracks were found to be completely closed at concrete surface temperatures of 75° F. for northern exposure and 85° F. for southern exposure. Measured opening of cracks as temperatures fell below these values correlated very well with computations based on the standard expansion coefficients commonly used for concrete. (SWC 4-gG1)

At Logan, Utah, concrete test linings installed in 1949 appeared to be sound and in good condition hydraulically but the maximum seepage rate, measured in 1963, was about 2/3 of the rate without lining. This loss was largely through unmaintained joints. Preliminary tests of methods for waterproofing the concrete and joints indicated that both butyl and polyisobutylene can be bonded to concrete and the bond will not be weakened by repeated freezing and thawing.

Other tests at Logan, Utah, have demonstrated that buried membrane linings of 8-mil vinyl and polyethylene film will provide ten years of near perfect seepage control. These linings, together with butyl and asphalt-burlap laminate are the most watertight of the linings evaluated. Pinhole defects in butyl rubber sheeting were discovered but the problem was solved by using a two-ply laminated structure.

Laboratory and field seepage control studies at Reno, Nevada, comparing dispersion treatments, surface blankets, and buried blankets of bentonite indicate the buried blanket is the most permanent. All bentonite seals were most effective if they were kept moist at all times. The soluble cations in each of 15 bentonite samples collected in Western United States were greater than 90 percent soluble sodium, whereas water-soluble calcium plus magnesium was present in only small quantities or not at all. (SWC 4-g3)

2. Evaporation from soil and plant surfaces. Temperature compensation has now been included in the design of the miniature net radiometer developed at the U. S. Water Conservation Laboratory. Uncompensated instruments were found to be in error by 6 percent over an ambient temperature range of 6 to 47° C. which could be serious in energy balance studies of evapotranspiration. The new circuit essentially eliminates errors due to instrument temperature over the range 20 to 47° C. which is of primary interest in the Tempe, Arizona area.

Studies at the U. S. Water Conservation Laboratory indicated that evapotranspiration from alfalfa was determined by meteorological influences until more than two-thirds of the available soil moisture had been depleted from the root zone. When soil moisture was above this level, water loss from the crop proceeded at a rate that could be arrived at from meteorological variables. This implied that the ability of the alfalfa to absorb, conduct, and transmit water through the leaves to the atmosphere did not significantly determine the rate of water loss. In other studies the height of alfalfa was shown to have a significant effect on evapotranspiration. With alfalfa at heights of 4, 12, and 20 inches, it was demonstrated that increasing height by a factor of 2 results in increasing the rate of water loss anywhere from 25 to 35 percent. This effect is attributed to differences in the roughness of the respective crop covers and the resultant increase in the efficiency of heat extraction from the overlying air.

The combination, or Penman, method of computing evapotranspiration was found to provide good estimates in studies at the U. S. Water Conservation Laboratory under conditions where availability of water for evaporation was not limiting. Hourly and daily estimates for open water, bare soil and well-watered alfalfa were made for widely different conditions occurring in 1961 and 1963. Standard hourly weather data, net radiation, and an estimate of surface roughness were used in the computations and the results produced good agreement with highly accurate weighable lysimeter data. Daily values were typically estimated within 5 percent or around 0.002 inch. Strong advective effects were properly accounted for. Hourly estimates, though less precise, indicated the diurnal pattern of radiation, windspeed, and vapor pressure deficit correctly. (SWC 4-gG2)

The validity of diffusion theory for describing water movement in soil has been confirmed by research at the U. S. Water Conservation Laboratory. Three independent methods were used to obtain diffusion coefficients over a range of soil moisture content. Comparison of the data showed that during

absorption of water by dry soil, the initial diffusion coefficient rapidly increases to a maximum value and then declines to a lower value as moisture content increases. The peak occurs at a moisture content where one molecular layer of water has formed on the soil particle surfaces. For drying, the peak value is lower, occurs at a higher water content and occurs more gradually.

A system utilizing gamma radiation for accurately measuring moisture in undisturbed thin layers of soil in the field was designed and calibrated at the U. S. Water Conservation Laboratory. Soil moisture is measured as a function of the change in gamma radiation caused by changes in soil moisture between a gamma source and a detector placed in parallel channels in the soil. Calibration procedures using glass-water models and actual soil columns confirmed the validity of assumptions made in designing the system. A two-minute measurement permits determining moisture content of 0.4 inch soil layers to 0.6 percent on a volume basis. (SWC 4-gG4)

3. Evaporation from water surfaces. A stable emulsion of long-chain alcohols reduced evaporation from 9-foot-diameter steel tanks by 35 to 45 percent when continuously applied at rates of ten pounds per acre per month in studies at the U. S. Water Conservation Laboratory. Mean daily water surface temperatures in treated tanks were about 3° C. higher than in untreated tanks and evaporation from treated tanks two days after loss of the surface film was over 30 percent higher than from the untreated tanks. This confirms other work which has shown that the film must be continuously maintained if effective evaporation reduction is to be obtained. The emulsion has continued to prove exceptionally stable and easy to apply with simple equipment. (SWC 4-gG2)

B. Development of Farm Water Supplies, Structures and Related Equipment

1. Water harvest. Studies at Tifton, Georgia, of farm ponds typical of those in the Southern Coastal Plain showed that ponds of the area may be recharged more by seepage from the saturated soil profile of the watershed than by surface flow. During the 1962-63 water year, surface flow into the experimental ponds was of short duration, whereas inflow from subsurface water although at a slow rate, occurred over a prolonged time from January to July when rains were adequate. One experimental pond, with 10 acre-feet storage volume built for a farm irrigation water supply, retained only 7.5 acre-feet or 22 percent of the water reaching the pond from the 60-acre loamy sandy watershed area to replace seepage and evaporation losses and the water used for irrigation. Irrigation in 1963, however, required only 2.2 acre-feet. This information will be used in determining optimum pond storage volume for utilization of available farm water supplies on Coastal Plain soils.

Irrigation pits characteristically are dug through an overburden of clay soil with poor water transmissibility into an aquifer of sandy material. These pits are recharged mainly in the winter and early spring months. In late summer and fall, unused water is lost from the pits back to the aquifer

zone. Pits located below a sloping area, such as those in Rains soils below Tifton loamy sand, may be subjected to some hydrostatic head that will cause excess water to overflow the pit banks after prolonged and heavy rains. Pits located in level areas are recharged from saturated aquifers that connect with intermittent sand lenses that extend close to the soil surface. (SWC 4-b1)

At McCredie, Missouri, studies on a 16-acre reservoir with a full storage of about 100 acre-feet and its 154-acre watershed have shown that the 1963 water yield of 2.7 acre-feet was the lowest during the 1941-1963 recording period. Combined net evaporation and seepage loss from the reservoir was about 18.5 acre-feet. Only about 35 acres could have been irrigated from the reservoir during 1962 and 1963. (SWC 4-c1)

The water harvest system, termed "rain traps," developed at Logan, Utah, for efficiently collecting and storing rain water for livestock has been installed at more than a dozen locations in the Fishlake National Forest, two on the Cache National Forest, and one on Bureau of Land Management property in eastern Utah. The system has been approved by Agricultural Stabilization and Conservation Service in several states as a conservation practice. One form of the rain trap, consisting of a butyl rubber catchment and a butyl rubber storage bag is now being sold commercially. (SWC 4-g3)

Field and laboratory studies at the U. S. Water Conservation Laboratory have shown that inexpensive asphalt emulsions are a satisfactory adhesive for bonding lap joints in thin plastic films used on water harvest catchment areas and other applications. Testing machine measurements on 2-inch lap joints made with butyl-modified asphalt emulsions showed that one day of curing produced full-strength joints on 1-mil Tedlar plastic film. Ten or more days of curing were required to develop a full-strength joint on 1-mil aluminum foil. Curing requires loss of water from the asphalt emulsion. Water vapor diffuses through the plastic film but not through aluminum foil. Accordingly, the emulsions are not a truly satisfactory adhesive for metal foil.

A heat-resistant chemical to increase rainfall runoff from water harvest areas by causing the soil to become water repellent was evaluated with promising results at the U. S. Water Conservation Laboratory. The material, sprayed on the soil surface caused the soil to become water repellent to a depth of over one inch. Effective treatment depth was found to be a function of solution concentration, soil texture, and total application rate. Runoff from a 10-square-meter plot treated on May 30, 1963, was approximately 80 percent of the 4.9 inch total rainfall after treatment. No erosion was observed on the treated sandy loam soil with a 3-percent slope. Cost of this treatment would be about 5 cents per square yard or 250 dollars per acre. (SWC 4-gG3)

2. Water measurement and control structures. Full-scale model tests on the constant head orifice (CHO) water-measuring device at Fort Collins, Colorado, show that under most conditions, the CHO provides accurate measurements of irrigation water if operated properly. Extreme caution is required in initially setting the differential head. An increase in tail-water, after the gate openings and differential head have been set, can cause a significant decrease in discharge. Therefore, when operating the structure, all gate adjustments should be checked after the upstream and downstream water levels have become stable. (SWC 4-d1)

A new type of gate for use in canals and ditches was developed at Logan, Utah. The gate is completely watertight and is low in cost. It consists of a length of lay-flat tubing bonded to a pipe through the canal bank. It is believed that this gate is suitable for precisely controlled diversion and metering of irrigation water. It should be more trouble free than conventional devices now in use. (SWC 4-g3)

Research at the U. S. Water Conservation Laboratory has shown that uncalibrated commercial pipe elbows can be used to measure flow with accuracy ranging from good to excellent, depending on the type of elbow used. These meters use the difference in pressure between the inside and outside of the elbow, resulting from forces imposed on the water as it flows around the bend, as a measure of the rate of flow. Tests of 23 short-radius cast iron elbows with diameters of 3 to 12 inches showed that the standard deviation of the discharge coefficient C ranged from 2.2 to 2.8 percent. Eight long-radius 3-inch-diameter cast iron elbows had a standard deviation in C of only 1.5 percent. Six 3-inch-diameter die-cast plastic elbows were even better, with a standard deviation of 0.8 percent for both long- and short-turn elbows. These studies indicate that discharge coefficients obtained from laboratory calibration can be used for properly installed uncalibrated elbows to measure water flow with standard deviation ranging from 1 to 3 percent, depending upon the type of elbow used.

Field tests showed that dye tracer equipment and techniques developed at the U. S. Water Conservation Laboratory can be used to measure water in large channels with less than 2 percent error. During three different trials on a canal with flows around 1,000 c.f.s., dye concentration in samples taken from the center and sides of the canal differed by 1 percent or less, showing that good mixing of dye had been obtained in the test reach of 1.2 miles. However, in another canal test with a flow of around 600 c.f.s. and double the amount of tracer, good mixing did not occur in a mixing length of 1.0 mile. The portable sampling and analyzing equipment performed very well under these actual field conditions. The tracer method is potentially capable of measurement at the 1-percent error level and other measurement methods capable of this accuracy are not readily available. (SWC 4-gG5)

3. Runoff water management. At Weslaco, Texas, three years of research on land leveling have shown no essential differences in moisture storage between crop seasons for leveled or nonleveled land. Leveled land may store

slightly more moisture in the soil profile following heavy rains than non-leveled land, but these differences do not persist through the long fallow period. Leveled land consistently shows more uniform moisture distribution across the field at planting time than nonleveled land. The difference in grain sorghum yield between leveled and nonleveled land has been inconsistent and small. Soil salinity and water table depth are more important factors affecting crop yields than leveling drylands for water conservation in the Rio Grande Valley of Texas.

Continuing work at Bushland and Big Spring, Texas, and Hays, Kansas, on Zingg conservation benches permits some conclusions. It now seems clear that on the fine-textured soils at Bushland, Texas, and Hays, Kansas, efficient use is made of precipitation and runoff water caught on the leveled benches. At Big Spring, Texas, however, on a coarse-textured soil and under the influence of a hotter climate, the conservation benches have not produced better utilization of precipitation than conventional farming systems. (SWC 4-13(e2))

The Zingg conservation benches are also under study at Fort Collins and Akron, Colorado; Mandan, North Dakota; and Newell, South Dakota. Results are reported under area 9. (SWC 4-d1)

C. Methods, Practices and Devices for Ground Water Recharge

At Bushland, Texas, geological strata were easily identified from the electric and gamma ray well logs secured in the exploration of soil and geologic formations under a playa lake and its watershed. Strata that have been identified by the well logs are lake sediments, top and bottom of the Ogallala formation, saturated and unsaturated sections of the Ogallala formation, clay lenses, and a medium gravel-sand layer commonly called "mortar beds." Other work has shown that surface electrical resistivity techniques are useful in the exploration of a playa lake and its watershed. Preliminary analyses show good correlation between resistivity plots and the known stratigraphy of the playa lake. This means that electric and gamma ray well-logging techniques can be used in conjunction with surface electrical resistivity in developing a rapid survey of subsurface strata under lakes in the Texas High Plains. Such information should be most useful in selecting sites for ground water recharge shafts, wells, and related works. (SWC 4-13(e2))

The application of an especially designed permeameter at Fresno, California, to core samples from field profiles has resulted in physical definition of the hydraulic properties of a deep (120-foot) perching layer in southwestern Fresno County. From this information the magnitude of vertical flow through the impeding layer has been calculated. Such flows can now be made a part of a ground water inventory to determine extent of aquifer recharge and/or how soon a drainage problem will result with future expansion of irrigation.

In studies concerned with salt movements under proposed recharge areas, laboratory leaching of Panoche sandy clay loam by unsaturated flow indicated that about half of the initial soil moisture (at 16 atmospheres tension) was retained or "bound" by the soil particles. This "bound" water did not appear to contribute to the leaching or displacement of anions. Chlorides and nitrates were leached downward 34 percent farther than they would have been under piston-type displacement. Chloride and nitrate ion concentrations in the displaced fraction of the original soil solution were about twice those contained in the initial soil solution existing at 16 atmospheres tension.

Sedimentation studies involving both air and sediment clogging gave hyperbolic velocity-time curves. Velocities for uniform 0.10-, 0.25-, and 0.50-mm. sands were all reduced from 2 to 10 feet per day within 50 hours by a water containing 500 ppm. of silt plus clay. Clogging took place between the surface and a point 0.50 foot below the surface in the coarse, medium and fine sands. This information provides an important clue concerning the permissible sediment content of water used for recharge.

Studies at Lompoc, California, show that the annual recharge of the ground water supplies of the Lompoc Plain resulting from deep penetration of rainfall and irrigation ranged from 6,600 to 24,500 acre-feet during the period 1957 through 1962. The irrigated area varied from 7,000 to 8,000 acres during the period, with annual application of irrigation water ranging from 18,700 to 26,500 acre-feet. The total local recharge of ground water from rainfall and deep penetration of irrigation water amounts to approximately 62 percent of the total pumpage for irrigation. (SWC 4-g2)

D. Reclaiming and Reuse of Wasted or Contaminated Waters

Three years of data on use of water by native grasses as measured in evapotranspiration tanks in the Humboldt Valley of Nevada show that grasses subjected to simulated wet meadow conditions (fluctuating high water tables are comparable to the current farmer irrigation practices) produced less hay per unit of water used than when grown under a well-managed constant shallow water table condition.

Phreatophyte replacement vegetation studies conducted in the Paradise Valley, a subarea of the main Humboldt Valley of Nevada, with assistance from the Crops Research Division and other project cooperators have shown that success of grass seedling establishment is directly related to the salt concentration of the soil extract and exchangeable sodium percentage. Large variations in soil alkalinity and salinity exist within short distances both vertically and horizontally. Line transect measurements in areas where re-vegetation is considered show two-thirds of the area is composed of playa soil that has high sodium-low intake rate characteristics. Such soil conditions, plus the fact that insufficient precipitation or irrigation water is available for leaching, presents the major problem for establishing a replacement beneficial vegetation in these desert phreatophyte areas. Ground

water depths and fluctuations, however, are as suitable for beneficial plants to grow as phreatophytes, provided seedling and root establishment can be accomplished. (SWC 4-g1)

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AREA 5: IRRIGATION PRINCIPLES, REQUIREMENTS, PRACTICES AND FACILITIES FOR EFFICIENT USE OF WATER ON FARMS

Problem: The efficiency of water use by irrigated agriculture is in general low. Competition now faced by irrigated agriculture from municipal and industrial users of water for the limited supplies available is forcing the adoption of improved methods of water application and use. While rigid adherence to historical methods of allocating water has not fostered efficiency, there are other reasons. These include a lack of knowledge concerning the most efficient irrigation methods and the cost of adapting currently available procedures. The existence of agriculture in arid areas depends on adequate water supplies. Irrigation has also become an economic necessity in the production of high-value crops in the humid areas where annual or seasonal droughts jeopardize both the quality and quantity of crops produced.

Solution to many of the problems associated with the irrigation practice, such as procedures for use of limited water supplies, efficient methods of water application, optimum time and amount of application in relation to crop growth stage, climate and soil factors, and a practical method of determining when to irrigate, would do much to increase water use efficiency. Temperature control by sprinkler irrigation to maintain high crop quality is an area needing further development.

The improvement of irrigation water requirement prediction equations requires the development of improved methods of computing (1) evapotranspiration, based on sound thermodynamic principles including the advective energy component; (2) deep percolation losses; and (3) effective rainfall probabilities. The shortage and cost of farm labor and the competition for water supplies stress the need for automation in irrigation water application by both sprinkler and surface methods.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in irrigation, utilizing agricultural and hydraulic engineers, soil physicists, and soil scientists. Work concerned with consumptive use, timing, and minimum requirements is underway in Virginia, Alabama, Georgia, Texas, California, Utah, and Nevada; with crop response to water and fertility in New Jersey, Virginia, Alabama, Georgia, Mississippi, Colorado, Nebraska, Nevada, South Dakota, Wyoming, Texas, and Washington; and with water intake, transmission, storage and deep percolation in New Jersey, Georgia, Texas, Washington, Oregon, Missouri, California, and Nevada. Surface irrigation hydraulics and water absorption is under study in South Dakota, Texas, Idaho, and Utah. Sprinkler irrigation techniques, water distribution and absorption

is under study in Idaho and Nevada. System design for efficient use of water and of labor in water application is under study in Colorado, California, Texas, Utah, Idaho, and Florida. This work is in cooperation with the state experiment stations or other agencies of the states in which the work is located. Three PL-480 studies on consumptive use, design of sprinkler systems and rates of sprinkler application are underway in Israel. The scientific and engineering effort in this area totals 24.0 professional man-years. Of this total, 13.3 are devoted to irrigation water requirements, crop response, and soil-water relations (including 1.3 for the PL-480 study); 2.3 to surface irrigation hydraulics and water absorption; 5.3 to sprinkler irrigation techniques, water distribution and absorption (including 3.7 for PL-480 studies); and 3.1 to systems design for efficient use of water and of labor in water application.

PROGRAM OF STATE EXPERIMENT STATIONS

The States are conducting both basic and applied research in irrigation. At many of the States the research is conducted cooperatively with the Department.

The response and water needs of practically all crops are being determined. The effect of irrigation on crop quality, quantity, uniformity of ripening, and many other factors are being determined. Basic research is also underway on the physiology of water movement into and through plants.

Research is underway to develop better design criteria for more efficient use of irrigation water. Included in this research are studies to determine optimum gradients of furrows and borders, optimum lengths of run and stream sizes, more efficient sprinkler systems, and on water intake rates as they affect design. Work is also being done on methods of determining when irrigation water should be applied for most efficient use of available water.

The total research effort in irrigation at the State experiment stations is 38.1 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Irrigation Water Requirements, Crop Response and Soil-Water Relations

1. Consumptive use, timing, and minimum water requirements. Current research in both humid and arid areas is directed towards increasing knowledge concerning the water requirements of crops, evaluating the factors affecting the water requirements, and determining the minimum amount of water required for economically satisfactory yields.

Disposition of energy at the earth's surface involves a knowledge of solar reflectance from various soil and crop surfaces. Reflectance measurements reported previously have been averages of several instantaneous values. At Fort Collins, Colorado, integrated ratios for a solar day obtained with two Eppley pyrheliometers, one mounted upward and the other downward, were in general agreement with values obtained by others. Extremes in reflectance ratios occurred over sugar beets and ranged from 0.14 to 0.29. Values for most crops including corn, barley, alfalfa and grass ranged from 0.20 to 0.25. Color of crop appeared to have little influence on reflectance but cultivation caused a marked reduction (0.24 to 0.15 when corn was about 6 inches tall). Reflectance ratios for black and white concrete surfaces were 0.47 and 0.14, respectively.

Evapotranspiration rates (E_t) of grass mixtures from lysimeters without similar border areas at Gunnison, Colorado, have been excessive when considered in terms of solar energy available to evaporate water. Peak use rates have exceeded 2.5 cms. per day for a two-week period. Subsequent measurements of E_t and the energy balance above lysimeters installed in a wet meadow under ideal conditions ranged from 0.50 to 0.83 cms. per day. These values were more realistic and were within expectations. Average E_t rates on all plots indicated that E_t equalled 1.11 net radiation (R_n). Sensible heat exchange from air to crop amounted to 0.08 cm./day or about 11 percent of total energy contributing to E_t. Heat flow to the soil was negligible. (SWC 5-d1)

A three-year study of relative turgidity as a basis for scheduling cotton irrigations at Weslaco, Texas, indicated that yields were not reduced when relative turgidity was maintained above 72 percent. The most critical stage for developing plant moisture stress was during bloom. On a deep, medium-textured soil which was wet to field capacity at planting, one or two irrigations during the blooming period, depending on rainfall, were sufficient to maintain the relative turgidity of cotton leaves above 72 percent. The optimum timing of two seasonal irrigations was the week following first bloom and three to four weeks after first bloom. One or two seasonal irrigations resulted in high yielding cotton of superior quality, and more efficient use of irrigation water than the common practice of three or four irrigations. (SWC 5-5(e1) Rev.)

At Thorsby, Alabama, yields of cotton were increased on Greenville fine sandy loam when the need for irrigation was determined by either measured pan evaporation, net radiation, soil moisture sampling, or the previously measured average rate of moisture use by cotton. No increase in yield resulted when irrigation applications were based on observed wilting of the plants. Water use efficiency was highest where irrigation need was based on net radiation.

Results at Watkinsville, Georgia, in 1963 showed that for the humid area, poor distribution of rain sometimes may be more important than lack of rainfall in determining the need for irrigation. The per-acre yield of Dixie 82

hybrid corn on Cecil sandy loam was increased from 98 bushels without irrigation to 155 bushels with irrigation, even though the rainfall was 5.38, 13.32, 3.91, and 2.54 inches in May, June, July, and August, respectively. At State College, Mississippi, one irrigation during a drought prior to tasseling had little effect on the yield of 25 experimental hybrids because ample rain fell after tasseling began. (SWC 5-b1)

Limited irrigation of grain sorghum at Bushland, Texas, resulted in high yields and more efficient use of water when it was applied during fruiting. Maximum water use efficiency of 540 to 620 pounds of grain per acre-inch was obtained from a 4-inch irrigation at milk stage. Irrigating for near maximum yields (7,600 pounds per acre) lowered irrigation water use efficiency to about 300 pounds of grain per acre-inch. Results indicate that limited irrigation in relation to critical stages of plant development offers opportunity for decreasing irrigation water requirements and using limited irrigation water supplies more efficiently. (SWC 5-5(e1) Rev.)

Studies over a six-year period at Lompoc, California, showed average annual evapotranspiration varied from 22.2 inches for beans to 39.4 inches for alfalfa. (SWC 5-g2)

In a study seeking to develop improved methods for estimating consumptive use of water by plants based on climatic data in Israel, preliminary analysis of results indicated the ten fruit and field crops under observation may be divided into two groups with significantly different mean evapotranspiration values. The group consisting of peaches, potatoes, and alfalfa had a mean value of 6.4 mm. per day, whereas all other crops combined to give a value of only 3.6 mm. per day. (A10-SWC-11)

2. Crop response to water and fertility. Orchardgrass irrigated with 11.3 inches of water at Blacksburg, Virginia, in 1963 yielded 1,925 pounds per acre more than did the nonirrigated grass. This increase resulting from irrigation during an extremely dry season was approximately 500 pounds per acre more than the increase obtained during 1962 when rainfall distribution was more normal. Nitrogen fertilization, however, affected yields more than did either irrigation or cutting treatments. With the exception of the 300-pound-per-acre rate, yields increased linearly with increasing amounts of nitrogen up to 600 pounds per acre applied in 1963. This was comparable to results obtained the previous two years. Irrigation did not appreciably influence the efficiency of utilization of applied nitrogen.

Also at Blacksburg, Virginia, using two varieties of tobacco, Ky. 16 and Ky. 16 Mammoth, evapotranspiration, as determined by barrel lysimeters, was 0.138 inch per day for the Ky. 16 as compared with 0.211 inch for the Ky. 16 Mammoth. Evapotranspirative losses per unit leaf area were almost 38 percent greater for the Ky. 16 variety, however, than for the Mammoth variety, indicating a greater efficiency of water use by the latter. (SWC 5-a1)

Interrelations of soil moisture and soil fertility were apparent at Watkinsville, Georgia, on sandy loam where three irrigations totaling 5 inches gave cotton yield increases of 192, 932, 1,007, and 1,100 pounds per acre when nitrogen applications were 0, 60, 120, and 180 pounds, respectively. The cotton yields without irrigation were 1,823, 1,685, 1,689, and 1,596 pounds per acre, respectively, for the four nitrogen rates, indicating that additional soil moisture was needed for the added nitrogen to be effective. The average yields of seed cotton on Greenville fine sandy loam at Thorsby, Alabama, were 3,374 and 2,492 pounds per acre with and without irrigation, respectively.

The yield of 25 experimental corn hybrids at State College, Mississippi, ranged from 87 to 185 bushels per acre, indicating differences in genetic ability to respond to adequate soil moisture and fertility. A comparison of male sterile versus male fertile strains in four single-cross hybrids showed sterile/fertile yield ratios of 80, 107, 111, and 115 where soil moisture was adequate, further indicating response differences due to inherent genetic ability. Three hybrids that were known to respond differently to various levels of soil moisture, when subjected to adequate soil moisture in 1963, gave yields that correlated positively with leaf-area index and inversely with number of stomates and number of trichomes per unit area of leaf.

A combination of irrigation to maintain soil moisture tension at less than 0.8 atmosphere and nitrogen applications up to 70 pounds per acre gave the highest market value return from flue-cured tobacco at Tifton, Georgia, during the 1955-63 period. Lowering the quantity and/or quality of the tobacco leaf resulted from either more or less soil moisture and/or nitrogen. Damage was not excessive, however, from temporarily flooding the crop by rain following irrigation on the well-drained Tifton loamy sand. (SWC 5-b1)

Clear plastic has been used to improve the germination of various seeds planted during cool seasons. The plastic maintains the soil moisture content at a higher level near the surface and increases soil temperature. Studies at Prosser, Washington, have shown that the air space between the soil and plastic is a major factor causing increased soil temperature. A clear water emulsion latex (used as an antitranspirant in the transplanting of trees) did not increase soil temperature materially. This study indicated that clear liquid sealants cannot be substituted for plastic film when increased soil temperature is desired for early germination of seeds.

Previous exploratory studies indicated that during the regrowth of alfalfa in the Columbia Basin, a condition known as "June Yellows" could be induced by maintaining a high soil moisture level prior to cutting. Further studies indicate that a continuous period of high soil moisture between cuttings may be required to induce this condition. (SWC 5-f1)

3. Water intake, transmission, storage and deep percolation.

Consumptive use does not include deep percolation losses between irrigations. The magnitude of unavoidable deep percolation losses is needed in planning and operating efficient irrigation projects. Studies at Prosser, Washington, indicated that water continued to move downward in the soil for two weeks after irrigating an actively transpiring crop even when water was added in amounts to minimize deep percolation. With heavier irrigations the magnitude of deep percolation losses between irrigations would increase. (SWC 5-f1)

At Logan, Utah, deep percolation of irrigation water below the root zone was approximately 25 percent of the total soil moisture depletion under a grain crop during a 65-day period. (SWC 5-g2)

Small plots are frequently used to determine field-capacity values for a soil. Studies at Prosser, Washington, indicate that on medium-textured soils underlain by coarse layers, plots larger than 30 feet in diameter are needed to reduce lateral flow to the surrounding drier area; otherwise, lateral flow barriers should be used. Lateral flow results in errors in field capacity values obtained.

Deep plowing soils of high silt content to depths of 36 inches is rapidly being adopted by farmers in southeastern Oregon as a corrective measure on what are locally known as "slick spot" soils. These soils have numerous small areas that are high in sodium near the surface and usually are saline. Intake rates on both the nonsaline areas and saline areas four years after plowing are almost twice as great as on nonsaline soils that were not plowed. Thus, deep plowing improves the entire field instead of just the "slick spot" areas. (SWC 5-f1)

At Watkinsville, Georgia, determinations of physical properties of soils that relate to irrigation on 71 soil sites show that soils of the Southern Piedmont are so variable they cannot be characterized on the basis of soil-type name alone. Such properties as moisture desorption characteristics, bulk density, available water capacity, and textural composition sometimes vary more within a soil series than between series. Aggregation, infiltration rates, and amount of moisture retained in the soil between 1/3 and 1 bar tension were increased in Cecil sandy loam where corn was grown in rotation with rye, fescuegrass, or Coastal bermudagrass, as contrasted to where corn was grown continuously. Even so, there was little difference in the number of "drought days" for corn in 1963 grown in five cropping systems that ranged from continuous corn to corn after three years of grass sod. (SWC 5-b1)

At New Brunswick, New Jersey, studies to determine the contribution of the upward movement of soil water to plant growth indicated that lateral movement into a dry Collington sandy loam soil was more rapid than vertical movement from a perched water table where a growing crop was used to

establish a water gradient. It took about four days for the soil in the center of a 23-inch-diameter column to be wetted to field capacity by lateral movement after the crop was removed. It took 45, 15, and 7 days, however, for the soil to be wetted to field capacity at 14-, 21- and 28-inch depths, respectively, by upward movement from a water table established at a depth of 65 inches. (SWC 5-a1)

B. Surface Irrigation Hydraulics and Water Absorption

A two-year furrow intake study on irrigated Pullman silty clay loam at Bushland, Texas, indicates that this soil has a high initial intake rate which rapidly drops to a very low basic rate. One to two inches of initial intake occurs during and soon after water passes a point in the furrow. The intake rate then rapidly declines from about 0.6 inch per hour, for the first hour after runoff begins from a short furrow segment, to a basic rate of 0.1 inch per hour or less about four hours later. This intake characteristic permits obtaining rather good distribution of water storage with length of run by cutting off the water soon after it reaches the end of the furrows, thus decreasing tailwater runoff losses and increasing water application efficiency. The generally recommended practice of getting the water to the end of furrows in one-fourth to one-half the duration of irrigation results in excessive runoff and lower water application efficiency on this soil. (SWC 5-e1)

At Logan, Utah, an equation was developed for the maximum continuous rate at which a specific amount of irrigation water can be applied without causing runoff. This equation is of the form: $Im = (CnD^{(n-1)})^{1/n}$, where Im is the rate of application when D inches of water have been absorbed. C and n are constants found in the generally accepted infiltration equation $D = CT^n$. Based on field experiments, rate of advance of an irrigation stream down a border was found to take the form: $T = a - a\,e^{cx}$, where T is the time in minutes required for the water to reach a distance x feet; a and c are constants; and e is the natural logarithm base. These equations illustrate the complicated phenomenon of infiltration of water into soils which is affected by many variables and is the basis for good irrigation design. (SWC 5-g1)

C. Sprinkler Irrigation Techniques, Water Distribution and Absorption

A portable device previously developed and reported for determining intake rates when applying water by sprinklers was used to evaluate intake rates on a sprinkler-irrigated farm with Scism and Melba silt loam in southwestern Idaho. The lowest rates obtained were: 0.18 inch/hr. on the bottoms of furrows between potato rows, 0.25 on bare ground, 0.30 on first year alfalfa, 0.44 on the tops of ridges in a potato field, and 0.56 on wheat stubble. Runoff occurred from the potato field during irrigation. The sprinkler system used on the farm applied water at rates equal to or lower than the minimum measured with wind condition less than 3.5 miles per hour

and when operated at 40 pounds of pressure. Winds of ten miles per hour increased the application rates on a part of the area to 0.25 inch per hour and accounts in part for the runoff. Tests on another nearby farm with the same type of equipment indicated application rates up to 0.29 inch per hour with operating pressure at 60 pounds and winds of 5.7 miles per hour. Thus, the application rate throughout the wetted area for sprinkler heads under various wind conditions and operation pressures are needed to permit designing efficient irrigation systems. (SWC 5-f2 and SWC 5-g3)

D. Systems Design for Efficient Use of Water and of Labor in Water Application

1. Irrigation efficiency. Improvement of irrigation systems for efficient utilization of irrigation water is highly essential in view of increasing competition for available water supplies in the West. The low-cost border-basin irrigation system developed at Hayden, Colorado, (7,000 feet elevation) required only 19.6 inches of water to produce 5.5 tons of alfalfa hay. All water applied remained on the field (no runoff). Water use efficiency was 3.6 acre-inches of water per ton of hay. Average consumptive use rate for the season was 0.18 inch per day. (SWC 5-d1)

In the Arlington Highlands area, near Pomona, California, irrigation efficiencies were determined for two citrus orchard watersheds using measurements of irrigation and precipitation as inflow and of runoff as outflow. Underlying bedrock prevented any unmeasured outflow. Average peak irrigation applications were 7.0 acre-inches in July, with a peak monthly evapotranspiration of 4.95 acre-inches. Monthly irrigation efficiencies varied from about 40 percent to nearly 70 percent, with the higher efficiencies occurring during the principal irrigation season. The lower efficiencies occurred during those months when some rain fell. (SWC 5-g2)

2. Automation. Interruption of flow in a farm irrigation ditch is a common occurrence. Such interruptions result in extra work repriming syphon tubes or if not noticed, result in overtopped and washed out ditches. Preliminary tests have been conducted at Twin Falls, Idaho, on a syphon tube that would hold its prime even though the flow of water in the ditch has been interrupted. (SWC 5-f2)

3. Subirrigation. Flow rate of porous tile installed for subirrigation of Tifway Bermudagrass decreased with time at Fort Lauderdale, Florida. Laboratory studies indicated the reduced flow rates may have been caused by chemical precipitation within the tiles as the irrigation water was highly mineralized. Soaking unclogged tile in distilled water for three days resulted in increased flow rates. Treating the installed porous tile with sulfur dioxide gas and dilute nitric acid increased the flow rate some, but not enough to meet the moisture needs of the bermudagrass. Laboratory trials showed some success in maintaining the flow rate by lowering the pH of the irrigation water. (SWC 5-b1)

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AREA 6: DRAINAGE PRINCIPLES, REQUIREMENTS, PRACTICES, AND FACILITIES FOR PROTECTION OF CROPS AND SOILS

Problem. Excess water is the dominant hazard to 245,563,000 acres or 17 percent of the land in the United States.[3/] For the cropland area, excess water is the dominant problem on 59,906,000 acres or 14 percent. Water management systems have been applied to some 140,000,000 acres of potentially wet lands in the United States. More than 90,000,000 acres are in organized districts and the remainder are individual farm enterprises. The U. S. Census Report for 1960 shows an expenditure during the last ten years for new drainage work of nearly $186,000,000 and a cost of maintenance, operation, and repair of more than $231,000,000.

There are numerous water management problems on these lands. High water tables during the spring restrict root development, which lowers the plants' drought resistance during the dry periods that generally follow. Water ponded in microtopographic depressions delays plantings beyond optimum dates, and makes the use of modern high-speed farming equipment uneconomical. Hillside seep areas function similarly to reduce farming efficiency. Conventional methods of subsurface drainage are costly. Precise information on the drainage requirements of many crops is not available.

The economic success and feasibility of many irrigation projects depend upon adequate subsurface drainage to prevent salting out and abandonment of the projects. On more than 50 percent of the total irrigated acreage, drainage is a necessary complement for successful operation.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of land drainage utilizing agricultural and hydraulic engineers, soil physicists, and plant physiologists. Surface drainage problems including land-forming, cut-fill effects and remedial treatments, row and drain specifications, and systems design for humid areas are under study in Virginia and Louisiana. The application of new materials and development of installation equipment and techniques for subsurface drainage are underway in Ohio, Minnesota, Colorado, North Dakota, Texas, Utah, and California. Interception drainage for the control of seeps on hillsides, below impoundments, and other special areas is being studied in Vermont and Wisconsin. Drainage of

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3/ U. S. Department of Agriculture, Agricultural Information Bulletin 262, 1962.

irrigated and other salt-affected lands to control ground water level and salinity is under study in North Dakota, Texas, Nevada, and California. The drainage requirements of crops is being studied in Virginia, North Carolina, Florida, Texas, and Nevada. Laboratory studies of soil properties, flow in porous media, analog and computer programs for systems design are underway in Ohio, Georgia, Utah, Minnesota, Colorado, and Texas. The performance of drainage systems including surface and subsurface systems alone and in combinations is being studied in Ohio, Florida, and Minnesota. The scientific and engineering effort in this area totals 20.0 professional man-years. Of this total, 2.6 are devoted to surface drainage problems; 4.0 to subsurface drainage--new materials, installation equipment and techniques, and hydraulics; 1.2 to interception drainage; 4.3 to irrigation drainage and drainage for salinity control; and 7.9 to design of optimum systems--drainage requirements of plants; soil properties, flow in porous media, analog and computer programs for systems design, and systems performance.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are conducting drainage research related to humid areas as well as on irrigated lands.

Research is being conducted on land shaping for improved surface drainage; effective depth and spacing of sub-surface drains; special problems on slowly permeable soils; and the effectiveness of pumping from underground aquifers for drainage. Studies are also being conducted on the feasibility of plastics sub-surface drains and the use of fiberglass as an envelope around drain tile.

Design and maintenance requirements of surface drainage systems are being studied. Research is also being conducted on the causes of ditch bank failures in surface drainage systems.

More rational design criteria for drainage systems on irrigated lands is being developed. Basic research is underway to determine the dynamics of water flow through various soils and into drains. Applicability of proposed drainage formulas is being tested by means of models and computer techniques. Part of this research effort is supplied by the cooperation of four stations and the USDA in Western regional research project W-51.

In addition to the work reported above, research is underway on general problems of drainage design and water table control. Much of the total drainage research by the States is in cooperation with the Department.

The total research effort in drainage research at the State experiment stations is 20.4 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Surface Drainage

1. Landforming, cut-fill effects and remedial treatments. Landforming for drainage of flatlands has been demonstrated to be effective, but yields are generally found to be less on cut areas where subsoil has been exposed than on fill areas. Current research at Blacksburg, Virginia, has been directed toward evaluating factors limiting production on exposed subsoils. A field study has indicated that once the nutrient deficiencies of the subsoil have been corrected, soil water availability is the major factor limiting plant growth. A straw mulch applied to an exposed Cecil clay subsoil at the rate of 3 tons per acre greatly increased the growth and quality of tobacco by decreasing evaporation losses and preventing surface crusting, thereby increasing the rate of water infiltration. Bare subsoil produced 136 pounds of tobacco leaves as compared with 256 pounds for the mulched plots. Tobacco from bare subsoil was valued at $52.69 per cwt. as compared with $65.50 for that from subsoil with the mulch treatment.

Greenhouse studies at Blacksburg, Virginia, were designed to give additional insight to the limitations of subsoils for crop production. Tobacco grown on a Cecil clay subsoil at two fertility and three soil moisture levels showed that yield depressions were obtained regardless of fertility level when soil moisture was allowed to drop below 75 percent of the total available water. To evaluate the interactive effects of soil moisture and growth stage, the growth period of tobacco was divided into three stages. At the low fertility level, no effect of growth stage was found, since nutrition was the major limiting factor. At the high fertility level, a growth depression was obtained only at the intermediate growth stage when soil water was allowed to fall below 75 percent of the available water. (SWC 6-a1)

Forming and five years of farming Mhoon clay loam in Louisiana has resulted in an 11-percent increase in bulk density of the 0- to 3-inch depth of the fill areas and a 9-percent increase in the cut areas. (SWC 6-b2)

2. Row and drain specifications and systems design. The improved surface drainage system developed in Louisiana for sugar cane was installed by 23 producers during the past three years. This system which eliminates quarter drains and increases production acreage by about 6 percent has worked much better than the old ditch system for both the removal of surface water and the efficient operation of production and harvesting machinery.

Silage production at Baton Rouge, Louisiana, averaged 9.3, 13.2, 14.9, and 18.8 tons per acre on Mhoon clay loam with precision graded rows having slopes of 0.10, 0.15, 0.20, and 0.25 foot per 100 feet, respectively. The average yield increase was 3.2 tons per acre for each increment of slope increase. There was no consistent effect on yields from row lengths of 500, 700, 900, and 1,100 feet on each row grade. (SWC 6-b2)

B. Subsurface Drainage

1. New materials - laboratory and field tests of performance. In Ohio, results show that three years after installation, the diameter of zipper-type plastic mole liners is still slightly larger than the overlap-types of liner, although in 1963, the diameter of the zipper-type liners decreased more than that of the overlap-type liners. Deformation of the zipper-type over the three-year period since installation has been from circular shape to pear-shaped, and now to more nearly a tear-drop-shaped cross section. This indicates the importance of a slit-closure procedure during installation that uniformly recompacts the soil surrounding the liner. Even though the drain diameters had decreased slightly, drain outflow rates produced by irrigating the three-year-old experiment were not significantly different from the flow rates recorded in 1962, indicating that conductivity rather than drain size determined peak flow rates. (SWC 6-c1)

At Logan, Utah, in the summer of 1963, mole drains with and without zipper-type plastic liners were installed at a 30-inch depth and at spacings of 20, 40, 60, and 80 feet. Early results show higher flow rates, better drawdown and more salt removal with the plastic linings.

Samples of four new drain tube materials are under laboratory test at Logan, Utah. They are: (1) Standard 4-inch-diameter concrete drain pipe; (2) non-rigid 3-inch-diameter zipper-type polyvinylchloride plastic drain liner; (3) zipper-type porcelain enamel steel drain tubing; and (4) fiber-glass-wrapped drain pipe. The initial tests on these materials revealed a wide variation in discharge rate between types, probably due to the distribution and total area of inlet openings along the drain tube. (SWC 6-g2)

At Weslaco, Texas, field and laboratory tests are being made on the hydraulic flow characteristics and strength of drainage tubing. Materials tested include semi-rigid plastic drain pipe, bitumenized fiber pipe, zipper-type porcelain enamel steel drain tubing, and fiberglass-wrapped drain pipe. All the materials tested are weaker than clay and concrete but have varying degrees of flexibility. The new materials because of their long lengths, can provide better alignment than is frequently obtained with short lengths of tile. (SWC 6-e3)

At Brawley, California, a tank study was made of root growth into drain lines constructed of clay or concrete tile with gravel filters and of bitumenized fiber pipe with a fiber glass mat filter. It was found that roots will grow into any of the three types of drains if the roots penetrate to the drain line level and if conditions for growth into the drains are favorable. In other words, the bitumenized fiber pipe does not prevent root growth.

Further studies have been made of fiber glass mat filter materials for agricultural drain lines. An attempt to develop an inexpensive transducer to measure pressure loading and deformation during actual installation has not been culminated. Criteria have been developed for fiber glass mat specifications which have been used by SCS in their tile drainage programs. (SWC 6-g2)

2. Installation equipment and techniques. At Columbus, Ohio, extensive field trials with the tool-bar-mounted mole plow showed that the plow design satisfied most of the desired performance characteristics. That is, the mole plow floated over a range of operating depths, the location of the mole plow hitch points alongside the crawler tracks provided dynamic stability for the tractor, and the hitch points could be easily and rapidly raised or lowered during forward motion, even when draft requirements were high.

The pendulum grade control system on the tool-bar-mounted mole plow was stable and accurate. Extensive field testing of the grade control system has shown that the speed of response for upward corrections of the hitch point must be nearly the same as that for downward correction; that the drain gradient is a function of the dampening and speed of response; and that the slope of the plow frame is not directly proportional to the drain gradient. (SWC 6-c1)

A trenching machine which will lay 4-inch-diameter plastic tubing in a 10-inch-wide trench has been developed in the Lower Rio Grande Valley of Texas. The narrow trench will decrease the soil loading by approximately one-half, compared to a trench 2 feet wide, and will greatly decrease the amount of soil that must be moved in the trenching operation. (SWC 6-e3)

C. Interception Drainage

The use of diversion terraces and tile drains is being studied in Vermont as a means of removing excess surface and subsurface water from sloping meadowlands. Instrumentation of the outlets of these structures has permitted a preliminary evaluation of the drainage treatments. After a heavy rain, following a long dry period, tile outflow hydrographs showed that there was some lag between rainfall and tile outflow initially, but once the soil became saturated, there was very little lag. Soil moisture data were obtained during a predominantly dry season. The only apparent effect of treatments was for tile placement: the 100-foot tile spacing caused the surface foot to be drier than did the 200-foot tile spacing or where no tile was used. No significant trend was observed for diversion depth or spacing with regard to surface soil moisture. Flow lines around the drains are being developed from piezometric data. (SWC 6-a1)

D. Irrigation Drainage and Drainage for Salinity Control

A three-year investigation of old tile drain systems at Weslaco, Texas, has shown that tile lines installed without envelope material gradually fill

with sediment. Analyses of sediment in old lines and observation of new lines show that, especially in sandier soils, the initial irrigation washes considerable loose backfill material into the drain lines. Accumulation of clay and silt continues until lines are partially or totally clogged. Over a period of years, clay soils that are predominantly montmorillinite move into the tile lines more readily than other soils. Several old tile systems installed with pea gravel envelope material had no accumulations of sediment. It appears from these investigations of old systems that a gravel envelope functions mainly in improving the hydraulic characteristics of water flow to and into the tile, and that this condition may result in less detachment of soil particles. (SWC 6-e3)

Drainage analog studies and experimental drain lines installed in the dryland area near Weslaco, Texas, have shown it may be necessary to drain the entire area simultaneously. The area includes over 100,000 acres affected by high water tables and salinity. The experimental lines discharged a great deal of water but piezometric studies show that water movement to the drains largely came from a sand aquifer, underlying the area at depths of from 7 to 15 feet. Although no artesian pressures exist, the tile lines create a hydraulic gradient which permits upward flow of water from the aquifer. Effective drawdown of the static water table extended only about 20 feet on each side of the tile lines. The electrical conductivity of the tile effluent remained fairly constant at 35 to 40 mmhos./cm., and was the same as that of the water in the sand aquifer. This is further evidence that water is entering the drains from the lower strata. (SWC 6-e3)

At Pomona, California, where a laboratory study of manganese and iron oxide deposits in tile lines is being made, anaerobic storage during the incubation period of soil-water-organic matter mixtures proved to be a very effective means of reducing and therefore dissolving iron and manganese. An experiment to test the effectiveness of various kinds of organic materials for this purpose showed that water-soluble carbonaceous types of organic materials were most effective. This procedure suggests an easy way to characterize soils as to their susceptibility to precipitate manganese or iron oxide compounds in tile line joints. (SWC 6-g2)

Use of the neutron method for assessing soil moisture content in drainage investigations under relatively high levels of soil salinity at Grand Forks, North Dakota, has shown that accuracy is sacrificed if the instrument is not field calibrated. Field calibration curves in saline soils depart widely from master calibration curves in nonsaline soils. The greater the salt content, the greater the deviation from the master curve. Chlorides made up about three-fourths of the soluble anions in these studies. Periodic calibration may be necessary for accurate measurement of soil moisture where soil salinity changes between irrigations, between seasons, or at other designated times. (SWC 6-d1)

At the U. S. Salinity Laboratory, Riverside, California, an intensive study has been made of unsaturated flow characteristics of irrigated soils. A knowledge of the soil-water diffusivity and the capillary conductivity of these soils is basic information needed for solution of many drainage, irrigation and salinity problems--i. e., rates of salination of soil profiles from saline ground water sources, rates of water loss by evaporation from field soil surfaces, availability of water to plant roots, etc.

A solution of the diffusion equation suggests that diffusivity can be calculated from the instantaneous outflow rate from a soil sample following even a large pressure change. A procedure called the "one-step" method has been developed based on this concept. Its advantages are (1) the size of the pressure increase is limited only by the bubbling pressure of the membrane; (2) considerable time is saved in the analysis of each soil sample because one equilibration replaces several; and (3) the questionable assumption of constant diffusivity over a range of water content is not required.

Drop-counting apparatus has been developed which provides an accurate means of recording the low rates of waterflow which prevail during the outflow processes of the one-step method. The water is separated from the outflowing air-water mixture and only the liquid flow rate is measured. Satisfactory precision of measurement has been obtained for flow rates ranging from 10 to less than 0.004 milliliters per hour. Evaporation losses within the drop-counting system are minimized by having the drop form in a small air-tight chamber and by keeping the other free-water surfaces covered with oil.

The "one-step" method used in conjunction with drop-counting apparatus for measuring the low rates of outflow represents a major step toward the routine and more rapid determination of soil-water diffusivity and of capillary conductivity. The capillary conductivity is calculated from the diffusivity data and the water retention versus suction relationship. (SWC 6-gF1)

E. Design of Optimum Systems

1. Drainage requirements of plants. Knowledge of the drainage requirements of specific crops is essential for better design of field drainage systems. Studies at Raleigh, North Carolina, using environment-control chambers, greenhouse, and open lysimeters, show that different crops respond differently to water table depth and degree of soil aeration. Fescue showed no differences in yield when grown at steady water table depths of 8 to 29 inches. Most of the fescue roots were located in the 0- to 4-inch soil layer. Yields of millet increased as depth to water table increased to 30 inches in loam and fine sandy loam soils. Kidney beans and string beans produced maximum yields at water table depths of 6, 12, and 24 inches in sandy loam, fine sandy loam, and silt loam, respectively, indicating drainage requirements are related to soil physical properties.

Preliminary data indicate that measurements of oxygen-partial pressure and oxygen-diffusion rates in the soil may be used to determine the depth to which soil is well aerated, and to determine the time required for the soil body to reach a desired oxygen level after being saturated. These factors are closely related also to depth of water table. Techniques are under development at Raleigh, North Carolina, to determine the oxygen consumption of intact root systems at different levels of oxygen concentration. This information is necessary to understand the effects anaerobic conditions caused by flooding have on normal activity of plant roots. Other procedures are under study to measure the rate of cell division in root tips as an indication of the response of roots to the level of oxygen and/or carbon dioxide. (SWC 6-b1)

2. Soil properties, flow in porous media, analog and computer programs for systems design. In a study of physical and chemical properties of soils in the Atlantic Coast flatwoods resource area, the pH of the soils was not decreased upon drying, indicating no acid susceptibility under aerobic conditions after draining. (SWC 6-b2)

A study of drainage characteristics of Fargo-Bearden soils in the Red River Valley of Minnesota has shown low hydraulic conductivities to 5 feet. However, these soils are rather uniform and no definite restrictive layer is indicated. Soil temperatures in the 3- to 5-foot depth remained at 32° F. or below until the third week in May. (SWC 6-c1)

At Castalia, Ohio, hydraulic conductivity measurements obtained by the auger hole method were not as accurate as those obtained in 1962 by computation from tile flow data. Two major limitations found with the auger hole method were that large cracks in the very dry clay soil tended to increase hydraulic conductivity values, and the volume of soil used for the auger hole measurement was much smaller than that involved in the tile outflow method. (SWC 6-c1)

Irrigation and drainage engineers are faced with the problem of getting water into or out of soil. In either case, the flow phenomenon involved is flow through partially saturated porous media. A theory relating the variables to capillary pressure, permeabilities of air and water, and saturation has been successfully verified in work at Fort Collins, Colorado. The theory can be used to predict one of the above variables if certain properties of the hydraulic media are known. It can also be used to describe the requirements for similitude between any two flow systems in porous media occupied by two immiscible fluid phases when the nonwetting phase is static and the flow of the wetting phase is described by Darcy's Law. (SWC 6-d1)

At Logan, Utah, research continued on a project to set statistical limits for the number of hydraulic conductivity samples needed for drainage design purposes. Samples from seven soil types and three depths representing 4,500 permeability determinations from the Imperial Valley were analyzed by

computer techniques. It was found that the number of samples needed to set confidence limits on a given soil type is the same for a large area as for a small area. The results of the analysis of Imperial Valley soils corroborate earlier results obtained from Australian data. (SWC 6-g1)

An analog study of the drainage of peat soils at Black Earth, Wisconsin, was conducted on the resistance network analog at Columbus, Ohio. Results of the study have indicated that a drain spacing of about 40 feet is necessary for adequate drainage during the wet spring period and that reduction of the hydrostatic pressure of the aquifer with vertical wells has little effect on the water table height midway between drains or on the required drain spacing. These results support similar field observations. (SWC 6-c1)

The design of drainage systems should consider such factors as the drainage requirements of crops, soil properties relating to moisture movement through the soil and retention of moisture in the soil, amount and frequency of rains, and other factors. Crop roots have a profound effect on soil moisture conditions. A mathematical model was developed at Raleigh, North Carolina, to describe the steady-state upward movement of water from a water table through soil in which active plant roots are present, and a theoretical analysis of the effect of various water-uptake patterns of roots was made. A theoretical analysis was completed of the probability of occurrence of a prescribed height of water table based on rainfall records. Work is continuing on these theoretical approaches to the design of drainage systems to eventually develop an empirical system that will consider all the factors important in such design. (SWC 6-b2)

3. System performance. At Castalia, Ohio, in 1963 there was a significant difference in corn yields between the no-drainage treatment and both the tile only and the tile plus surface drainage treatments. There was no significant yield difference between the no-drainage and the surface drainage only treatments as there was in 1962. Significant differences in yield existed among the different nitrogen-level applications (0, 100, 200, #N) for all the drainage treatments. The differences in corn yields resulting from nitrogen application were greater than the differences due to the drainage practices. (SWC 6-c1)

The subsidence rate of organic soils in the Everglades of southern Florida was slightly higher during 1958-1963 than in prior years because of more severe drought in the last five years. The average rate of subsidence for the past 50 years is 0.10 foot per year, and much of this area has only 3 to 4 feet of organic soil left above bedrock. A high water table is the most effective way of controlling this type of soil loss. Water table levels in experimental field plots responded quickly to changes in a drainage-irrigation control system at the Everglades Experiment Station, indicating high and low water tables can be managed for subsidence control, drainage requirements, and water requirements of crops in this highly important crop-producing area. (SWC 6-b1)

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AREA 7: SALINE, SODIC, AND RELATED SOILS PROBLEMS, AND QUALITY OF IRRIGATION WATERS AND THEIR RELATION TO PLANT GROWTH PROCESSES

Problem. Salinity continues to be a major problem in irrigated agriculture. In the arid West injurious concentrations of salts in the soil have impaired the use of 25 percent of the irrigated land. Fifty percent of this area is endangered. Salinity or brackish water problems in the eastern seaboard area have increased with the rapid expansion of supplemental irrigation in this area where tidal streams and creeks are a conveniently available source.

These salts move upward in the soil with soil water to supply evapotranspiration requirements and are left behind as the moisture passes to the atmosphere. This results in injurious accumulations in the root zone unless excess water as rain or overirrigation is periodically passed downward to leach the salts to the ground water or to a tile drainage system for removal in the tile effluent. These salts generally come from the irrigation water, although some soils naturally contain excessive quantities of harmful salts. When irrigation water contains a high level of dissolved salts, the problem is intensified. The nature of the salts, soil, and climatic conditions and leaching water quality create complicated problems, many of which have not been solved. The use of salt-tolerant plants offers relief, but these plants must be identified and developed. Disposal of salts without degrading water quality for the downstream user is a critical problem.

Research must continue to develop fundamental theories and principles concerning the relations of saline irrigation waters and salt-affected soils to the plant growth processes, and techniques for use of these principles in diagnosis and improvement of saline and sodic soils and waters in specific field situations.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research in the area of saline and sodic soils and quality of irrigation water for the growth and production of agricultural crops and ornamental plants. Scientists involved in this research include physicists, chemists, soil scientists, plant physiologists, agronomists, and agricultural engineers.

The center for basic research in this area is the U. S. Salinity Laboratory, Riverside, California. Studies deal with mechanisms of reactions in salt-affected soil and water and diagnostic techniques; physiological basis for tolerance of plants; adaptation and response of plants; water composition, ground water and salt balance; and leaching processes. AID projects in operation at the Laboratory are: (1) Salt and boron tolerance of plants of

special importance to AID missions; and (2) interpretation and adaptation of diagnostic and improvement techniques for AID use. Brackish water studies for the Atlantic Coast flatwood resource areas are centered at Norfolk, Virginia, with supporting work in New Jersey and Georgia. Salinity problems of the Rio Grande Plain and Lower Valley areas are under study at Weslaco, Texas, and those of the Red River Valley at Mandan and Grand Forks, North Dakota. Field station studies dealing with mechanisms of reactions and physical and chemical properties of salt-affected soils and waters are underway in North Dakota, Texas, and Virginia. A PL-480 study is underway in Israel. Studies of tolerance, adaptation and response of plants are in progress in Georgia, New Jersey, Virginia, and Texas. Water composition, ground water and salt balance studies are underway in California, North Dakota, Nevada, and Texas. Water, soil and crop management systems for saline and sodic soils are underway in North Dakota, Texas, California, and Oregon. Leaching processes are under study in Colorado, Montana, Texas, and Virginia.

The scientific and engineering effort in this area totals 25.0 professional man-years per year, nearly two-thirds of which is at the U. S. Salinity Laboratory. Of the total professional man-years, 6.5 are devoted to mechanisms of reactions in salt-affected soil and water, physical and chemical properties, and diagnostic techniques (including 1.3 for the PL-480 study); 9.0 to physiological basis for tolerance of plants, and adaptation and response of plants to salt-affected soil and water; 3.1 to water composition, ground water and salt balance; 3.5 to water, soil and crop management systems for saline and sodic soils; and 2.9 to leaching processes.

PROGRAM OF STATE EXPERIMENT STATIONS

Most of the Western states and one of the Southern states are conducting fundamental and applied research on saline and sodic soils and quality of irrigation water in relation to plant growth. Generally these investigations are closely cooperative with those of the Department. Expansion of the research programs in this program area is anticipated as soil salinity and water quality problems become more serious.

Reclamation investigations are underway in several states. In Colorado the effects of deep tillage and management of soils having hardpans or layered textured discontinuities will be determined. The chemical characteristics of slick spot soils and chemical means of increasing permeability is being examined by Idaho scientists.

In Arizona, research at the Safford Branch Station is largely devoted to salinity problems. The influence of bed shape and planting and irrigation practices on the germination, stand and yield of row-crops on saline and saline-alkali soils is under study. A new project is concerned with a comparison of sprinkler vs furrow irrigation with saline water in crop production.

The California, Hawaii, New Mexico and Washington experiment stations are participating in Western regional project W-82, Soils, Pesticides and the Quality of Water, which is concerned with the interactions between pesticides, soils and waters that may influence the degree of pollution of ground and surface waters. Emphasis is being placed on the mechanisms of movement of pesticides from the soil to the water supply.

Studies also are being made of the tolerance of citrus under field conditions where variable salinity conditions are built up in soil from use of irrigation waters of different quality, laboratory procedures for the diagnosis of salt-affected soils, the salt tolerance of various varieties of crops, leaching requirement for keeping salts out of the root zone, the lithium content of surface and well waters and its effect on crops, and the effect of various ratios and amounts of cations and anions on plant growth.

The total State research effort on soil salinity and water quality problems area is 10.8 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Mechanisms of Reactions in Salt-Affected Soil and Water, Physical and Chemical Properties, and Diagnostic Techniques

1. Mechanisms of reactions between dissolved and adsorbed constituents of salt-affected soils. At the U. S. Salinity Laboratory, Riverside, California, research has continued on estimation of exchangeable-sodium-percentage from solution cation composition. The exchangeable-sodium-percentage (ESP) is widely used to characterize the sodium status of arid-zone soils, and is the basis of the definition for sodic soils. Because an equilibrium exists between the solution and exchangeable cations in soils, it is possible to estimate exchangeable cation composition from solution cation composition. In 1954, the Laboratory staff defined the sodium-adsorption-ratio (SAR) of soil-water extracts and irrigation waters and showed that, for Western United States soils, the SAR of the saturation extract was highly related to the exchangeable Na/(exchange capacity - exchangeable Na) ratio (ESR) by the regression equation: $ESR = .01475\ SAR - .0128$ (1), and in turn, $ESP = 100(ESR)/(1 + ESR)$ (2).

The relation has recently been reexamined for an additional 186 soil samples from 24 countries. The regression equation obtained agreed closely with that found previously for soils from Western United States, and the coefficient of correlation was high ($r = 0.96$). It is concluded that equation (1) is generally applicable to arid-zone soils throughout the world, and that when combined with equation (2), it has a high degree of reliability for estimating ESP.

Work also continued at Riverside on pressure extraction of soil solution. Previous observations and calculations dealing with the progressive decrease in the salt concentration of the extract collected from a colloidal clay suspension have been extended to mixed-ion systems. It appears that the $Na/\sqrt{Ca}$ concentration ratio of the extract from $NaCl$-$CaCl_2$-montmorillonite clay increases as filtration proceeds. A possible explanation may be sought in the fact that the concentrations of Al and Si in the extract also increase during the filtration process. It is reasonable to assume that the Al^{3+} ion which enters the system during pressure filtration replaces adsorbed Na^+ in preference to adsorbed Ca^{2+}, and thereby increases the $Na/\sqrt{Ca}$ ratio. (SWC 7-gF1)

Cation exchange studies in Virginia with acidic soils and saline solutions confirmed previous results. Because of the presence of a pH-dependent charge in most soils, the exchange capacity determined with NH_4Ac (pH 7.0) does not have any significance in characterizing exchange reactions. The effective exchange capacity in these soils is determined by the equilibrium pH value of the soil-solution mixture. The degree of cation adsorption by a soil from a saline solution is, therefore, determined by the ionic strength of solution and the equilibrium pH value. Adsorption of Ca from a solution of $\underline{N}$ $CaCl_2$ buffered at pH 7.0 was close to predicted values and lower than exchange capacity values determined by NH_4Ac (pH 7.0). (SWC 7-a1)

The soluble salts in nonirrigated soils near Weslaco, Texas, are primarily chlorides of Na^+, Ca^{++} and Mg^{++} compose more than 50 percent of the salinity cations in the surface few inches of soil, but Na^+ dominates at deeper depths. The soils are saline-sodic according to classification standards, but no sodic soils have developed upon leaching because concentrations of Ca^{++} and Mg^{++} are sufficiently high to dominate the exchange complex when salt concentrations are lowered. (SWC 7-e1)

2. Physical and chemical properties of salt-affected soils. Because of the extreme importance of soil permeability in the management of irrigated soils, studies of the effect of mineral composition on the hydraulic conductivities of soil columns have been continued at the U. S. Salinity Laboratory, Riverside, California. Emphasis has been placed upon the standardization of techniques that give well-defined and reproducible K measurements, and upon the variation of the K of mineralogically characterized western soils with concentration and composition of the percolating solution. Montmorillonitic soils exhibited the most labile structure under high sodium-low salt regimes, soils containing amorphous or crypto-crystalline minerals and cementing agents had the most stable structure, and soils dominated by micaceous minerals were intermediate in their behavior. Detailed studies of the reversibility of permeability decreases upon the application of high-salt water revealed moderate to high reversibility for montmorillonitic soils, low to negligible reversibility for micaceous soils, and negligible reversibility for soils dominated by amorphous or crypto-crystalline components.

These results are interpreted as differentiating between situations in which swelling is the dominant sealing mechanism upon passage of low salt-high sodium waters, and situations in which dispersion and movement of particles is the dominant sealing mechanism. The studies are being continued to evaluate permeability data in terms of size and shape of conducting pores, and to determine threshold concentration and sodium-adsorption-ratio (SAR) values causing sealing of the different soils. The results will have considerable importance in predicting the effects of various management regimes on irrigated soils having varying mineralogical and structural relationships. (SWC 7-gF2)

Chemical and physical characterization of a saline-sodic soil in western North Dakota (Wade series) shows that its extremely slow permeability is due to large quantities of adsorbed sodium, thick fine-textured underlying horizons, and high soluble-salt content. The soluble salts are principally Na and $MgSO_4$. Soluble Mg was ten times greater than Ca, and SO_4 comprised more than 95 percent of the anions. (SWC 7-d1)

Differences between seven saline and nonsaline soil profile pairs at Weslaco, Texas, showed that: (1) the ground surface of saline sites averaged 3½ inches higher in elevation than adjacent nonsaline sites; and (2) surface slopes at saline sites averaged 0.31 percent as compared with 0.18 percent at nonsaline sites. The higher ground surface elevation and the greater slope of saline soils result in rainwater runoff from the slowly permeable saline soils, thus reducing the water available for leaching. (SWC 7-e1)

Further investigations during the past year at Riverside, California, on biological sulfate reduction in salt-affected soils have shown: (1) There is an approximate linear relation between the amount of sulfate reduction and the concentration of organic matter, whether indigenous or applied in the form of crop residues (straw). The reduction was about 0.5 unit of sulfate per unit of organic matter, on a weight basis, for mineral soils containing native organic matter in the range of 0.5 to 5 percent. For soils amended with straw at rates of 0.25 to 1.0 percent, the reduction was about 17 times greater than that found in soils containing an equal amount of organic matter in the native state. (2) Sulfate reduction was quantitatively related to the reaction products formed therefrom. For example, in all cases the addition of one unit of straw to calcareous soils of widely varying texture reduced sulfate about 0.5 unit. For each unit of sulfate reduced, salinity decreased about 0.2 unit, and the sodium hazard of the soil increased (50 percent for a clay soil and 100 percent for a loam soil). (3) The decrease in salinity was largely due to a decrease in the soluble Ca + Mg and to a smaller extent to a decrease in soluble sodium. The results indicate that the maximum changes in salinity and sodium hazard of poorly drained saline soils due to biological reduction of sulfate can be estimated from measurements of the organic matter content of the soil and of concentrations of sulfate in the soil solution. (SWC 7-gF2)

3. Diagnostic techniques. At the U. S. Salinity Laboratory, Riverside, California, an in-place method for field salinity appraisal has been developed, and preliminary tests have shown the method to be reliable and applicable for several purposes, including measurement of salinity changes during leaching. This method consists of imbedding in the soil a permeable ceramic cup that is fitted to a plastic tube with connections for applying suction. A sample of the soil solution is drawn into the cup by suction and the salt content is determined by measuring the electrical conductivity.

Three types of electrical conductivity cells have been developed to meet the requirements of different usages: (1) probe cell; (2) flow-thru cell; and (3) cup cell. The probe cell is designed to be carried to the field and used to measure the electrical conductivity of the soil solution in a number of sampling tubes by moving it from one tube to another. The flow-thru cell is installed within the sampling tube semipermanently with the electrode chamber near the bottom of the ceramic cup. It is designed to allow for more or less continuous monitoring of the electrical conductivity of the solution drawn into the ceramic cup and through the cell electrode chamber. The cup cell is constructed as an integral part of the sampling tube with the electrodes in a cup-like chamber below the permeable ceramic. In this case, the ceramic is a cylinder at the bottom of the plastic sampling tube. This type of cell is designed for use where the quantity of solution drawn into the cup is very small. Only 1.5 ml. of solution is required for the cup cell, whereas, approximately 3 to 4 and 5 to 10 milliliters are required for the flow-thru and the probe cells, respectively. (SWC 7-gF3)

A new method has been developed at Riverside for determining the gypsum content of soils, a constituent recognized as beneficial for improvement of sodic soils. As a result of a reexamination of the acetone method, an alternate method has been developed that obviates the use of acetone while retaining the advantages of the original method. The method consists of adding an excess of powdered gypsum to a soil-water extract and measuring the increase in the electrical conductivity. The increase in conductivity is related to the initial gypsum content of the soil. Measurements take into account the solubility of gypsum in the soil solution which is considerably higher than in water. Known amounts of gypsum added to soils were recovered within an accuracy of 6 percent. The modified method is rapid and can be performed with a modest outlay of equipment. (SWC 7-gF3)

Since many of the physical and chemical properties of soils are a function of the type and proportion of clay minerals present, study of methods for analysis has continued at Riverside, California. This has led to the adoption of total potassium, selective solubility in 0.5 N sodium hydroxide, and solubility during potassium pyrosulfate fusion as reliable criteria for the estimation of mica, quartz plus feldspar, allophane, and colloidal silica in such soils. The use of simultaneous equations involving surface area, cation-exchange-capacity and water loss data then allows estimation of the montmorillonite, vermiculite, and chlorite content of the soil clay. Application of such a scheme to over 50 arid-land soils has

yielded self-consistent analyses in qualitative agreement with those obtained from X-ray analyses. Differences between the proportions of minerals estimated by the two methods provide an insight into the microstructural relationships existing in the clay packets of a given soil. (SWC 7-gF3)

Leaf temperatures of cotton plants, at Weslaco, Texas, growing on saline soils caused by a high water table, were found to correlate well with the soil salinity in the 0- to 5-foot profile. This points to potential possibilities for remote sensing and detection of saline soils from the air, using instrumentation with sensitivity in the 8- to 12-micron wave length range. Previous photogrammetry studies using infrared film sensitive in the range of 0.9 micron explored successfully the relation between tonal contrasts on infrared pictures and soil salinity. (SWC 7-e1)

B. Physiological Basis for Tolerance of Plants and Adaptation and Response of Plants to Salt-Affected Soil and Water

1. Physiological effects of salts. Studies at the U. S. Salinity Laboratory, Riverside, California, on the effect of salinity upon water loss by plants using bell peppers and cotton have shown that the application of saline irrigation water causes decreases in the water and osmotic potentials of plant leaves as well as a decrease in the water potential of the soil. As a result, the gradient between the water potential of the plant and soil remains about equal to that for a nonsaline soil. When the relative rate of water loss from plants is plotted as a function of the water potential of either the soil or plant, the effect of salinity is essentially a displacement of the curve toward lower water potentials. (SWC 7-gF4)

Current studies at the U. S. Salinity Laboratory, Riverside, California, have shown that the water potential, formerly called diffusion pressure deficit, of excised leaves is about equal at temperatures of 15 and 25° C. Temperature also has little effect on the osmotic potential of the leaf, after proper correction for temperature effects on solute activity. Within the precision of measurement for beta ray gauging, the water content of the leaf, as indicated by leaf thickness, is unaffected by excision. This increases confidence in estimation of the water potential and osmotic potential of intact plants, as determined with the thermocouple psychrometer. Recent experiments show that salinity produces about equal decreases in the water potential and osmotic potential of plant leaves in addition to the decreases that occur as the soil dries. Consequently, the turgor potential remains about equal for plants in nonsaline and saline soil at a given water content. When the leaf-water content is plotted as a function of the plant-water potential, the curve is displaced toward lower water potentials.

One of the most significant findings is the fact that there seems to be a rather marked decrease in the modulus of elasticity of the cell walls at a turgor pressure of about 2.5 bars. This was observed in cotton, birdsfoot trefoil, sunflower, and pepper. This provides a simple physical explanation

for the phenomenon of permanent wilting, since this change occurs at a leaf suction of about 13 bars, a value in good agreement with the value of 15 bars of soil suction usually associated with permanent wilting.

Final proof that salinity limits cell division, assuming a constant amount of DNA per cell, required the comparison of DNA analysis with actual cell counts. These comparisons have now been made and they confirm, unequivocally, the limiting effect of salinity on cell division. The amount of DNA per leaf cell is constant under normal conditions so the amount per leaf is a good measure of cell number. As these studies have shown that the area of bean leaves increases in direct proportion to the increase in cell numbers, and that there is little or no effect on this relationship by salinity, the difference in size between normal and stunted leaves is due to the difference in the number of cells. Since the average number of cells per unit leaf area tends to remain constant, leaf thickness is solely a function of cell size.

Leaf-growth studies at Riverside have indicated a very important distinction between two types of dividing cells. Cell division in expanding leaves is carried on by relatively large vacuolate cells which are only temporarily affected by salination. Cell division in the auxiliary buds of the same plants is carried on by true, nonvacuolate, meristematic cells. Salinity permanently suppresses division by these cells. It seems likely that the more mature, vacuolate cells are less severely affected because they have developed an osmoregulatory system, lacking in meristematic cells, that enables them to compensate for salination. The difference in the response of these two types of cells helps to explain why salinity is similar to drought in some ways and very different in others. Both kinds of stress would be expected to suppress the uptake of water by meristematic cells but only drought should have this effect on vacuolate cells. Experiments with isolated plant tissue indicate that this is in fact the case. Vacuolate cells of isolated leaf tissue can adjust to 2 or 3 atm. of mannitol, a solute which they cannot accumulate. The latter stress is analogous to drought and the results show how an increase in the leaf suction of only 1 or 2 atm. can limit growth. Leaf suction begins to increase when the soil suction exceeds about 2.5 atm. and becomes limiting for growth well below a soil suction of 15 atm. Thus, there is basis in fact for the empirical practice of irrigating when the soil suction reaches about 2 atm. (SWC 7-gF6)

2. Tolerance of economic plants to salts. Research on salt tolerance of sugarcane at the U. S. Salinity Laboratory, Riverside, California, has given valuable insights into the salinity responses of sugarcane. Twenty-six hours of sprinkling with waters containing 15 meq./l. of chloride salts with five combinations of cations produced only small increases in salt content of leaves and stalks. Reputed salt damage to sugarcane by sprinkling probably results from accumulated soil salinity rather than direct foliar absorption of salt.

Salinity effects on cane yield are linear up to 10 mmhos./cm. (EC_e). Cane yields decreased by 50 percent at about 8 mmhos./cm. in the greenhouse and at about 10 mmhos./cm. in the field plots. The variety NCo-293 in both experiments produced larger yields and was somewhat more salt-tolerant than NCo-310. In the field plots, sulfate salts were somewhat less inhibitory than chloride, and a high proportion of $MgCl_2$ was more inhibitory than $CaCl_2$--NaCl mixtures. Sugar analysis of stalks to date indicates that low salinity increases sugar percentages but moderate to high salinity decreases sugar content.

Research on salt tolerance of safflower during 1963 has largely confirmed the salt-tolerance data previously reported. An earlier planting date this year gave maximum yields 44 percent greater than the previous year. Low salinity stimulated seed yield more this year than last. At 5 mmhos./cm. (EC_e), yields were 20 percent greater than for the nonsaline plot. Average yield at 8 mmhos./cm. was still more than 90 percent of the maximum, but seed yields decreased rapidly at higher salinities, averaging 56 percent of the maximum at 12 mmhos./cm.

Analysis of seed from the 1962 experiment revealed a significant decrease in oil percentage but no effect of salinity on fatty acid composition of the seed oils. Seed oil percentage decreased linearly with increasing salinity and averaged 14.6 percent less at a salinity of 11 mmhos./cm. than for the nonsaline condition. Thus, although salinity affects oil content only about half as much as it affects seed yield, the lowered oil content was a significant factor in reducing oil yields. Despite these effects at higher salinity, the excellent performance of safflower at moderate salinity distinguishes it as a crop well adapted for culture under saline conditions. (SWC 7-gF5 and SWC AID-0-1-2)

In a second series of experiments at the U. S. Salinity Laboratory, Riverside, California, on salt tolerance of 13 new species of ornamental shrubs, none appears as salt-sensitive as the previously studied rose and pineapple guava, but Hibiscus and Dodonea have been severely injured. Dodonea, like Xylosma, is particularly sensitive to sodium, and Hibiscus has been severely injured by chloride. Observations during 1964 should distinguish the moderately tolerant from the highly tolerant shrubs in the current tests. Information on the salt tolerance of ground covers and shrubs has been of particular interest to highway landscaping engineers and municipal water districts. Research is underway on chloride accumulation by grapes. (SWC 7-gF8)

Data was obtained for the second year in Virginia on a study in which saline water was used for supplemental irrigation of vegetable crops at three locations: Fleming, Ga., Norfolk, Va., and New Brunswick, N. J. The spring crop of snapbeans was irrigated at all three locations. In Georgia, the fresh-water-irrigated plots yielded twice that of the nonirrigated, and the increase due to irrigation in New Jersey was almost sevenfold. At both locations there was a yield reduction with increasing salinity. This

reduction was appreciable because of the relatively young growth stage at which the saline water was applied. No response to irrigation was obtained at Norfolk, Va. In general, crop response to saline water irrigation is readily predictable if the salt tolerance of the growth stage of the specific crop is taken into consideration as well as the potential level of soil salinity which may result from irrigation with water of specified quality.

In Georgia, there was no advantage from irrigation with a concentration of about 3 mmhos. and above, as the yields were less than from the plants not irrigated. Yields of turnips, collards, and kale were doubled by irrigation with pure water. These crops were more tolerant than beans to salt, and light concentrations had little effect on yield. Irrigation with salt concentrations up to 6 mmhos. gave increases of 50 percent over the plants not irrigated. (SWC 7-a1 and SWC 7-b1)

A greenhouse study in Virginia, carried out to evaluate the interactive effects of salinity and fertility on the growth of tomatoes, showed a pronounced increase in yield for all treatments receiving P. Although tomato yields for all fertility treatments decreased with increasing salinity, the yields for the high-salinity level of the P-treated pots were greater than the nonsalinized, unfertilized control. In general, the effect of salinity on yields was dependent upon the general soil fertility level and not related to any specific element. Plant composition was predominantly influenced by the salts added in the saline irrigation and, to a lesser extent, by the plant nutrients added.

Studies to determine the effect of salinization of a portion of the root system on the growth and consumptive use of water by plants, using tomatoes and corn as test crops, showed that apparently normal growth was maintained with one-third and, in some instances, two-thirds of the root zone salinized. Partial salinization resulted in reduced transpiration. For corn, salinization of a portion of the root system did not appreciably reduce the total amount of water used nor the amount of water used per unit weight of plant material. For tomatoes, the total amount of water used was reduced by salinization of part of the root system as well as the amount of water used per unit weight of plant material. As salinization increases in one portion of the root zone, water uptake from that zone decreases and eventually ceases and correspondingly more water is absorbed from the roots in the nonsaline zone. (SWC 7-a1)

In the laboratory at Weslaco, Texas, presoaked grain sorghum seed emerged about one day earlier than unsoaked seed at salinity levels of 1.4, 6.0, 10.0 and 16.0 mmhos./cm. Presoaking increased emergence slightly (maximum of 26 percent) where soil moisture exceeded 1/3 atm. and the salt level of the saturation extract did not exceed 10 mmhos./cm. The critical total soil moisture stress for RS610 grain sorghum germination was found to be approximately 8 atm. (SWC 7-e1)

C. Water Composition, Ground Water and Salt Balance Studies

A new index of the tendency of calcium carbonate to precipitate from irrigation waters of various composition has been developed at the U. S. Salinity Laboratory, Riverside, California. The index (designated pH_c) is readily calculated from standard water analyses and prepared graphs. Irrigation waters having pH_c values of less than about 8.3 tend to precipitate calcium carbonate, whereas waters having values greater than about 8.3 tend to dissolve it. For waters which tend to precipitate calcium carbonate, a close linear relation was found between calculated pH_c values and the logarithms of the quantities of carbonate that precipitate when the water is equilibrated with calcium carbonate.

A study of Salinity Laboratory data on accumulation of exchangeable sodium by soils irrigated with high-carbonate waters showed that accumulation is influenced jointly by the SAR and the pH_c values of the waters, and can be expressed approximately by the empirical equation:

$$\text{Exchangeable-sodium-percentage} = 2SAR + 2SAR\ (8.4 - pH_c)$$

This equation satisfactorily described the accumulation of exchangeable sodium in ten field soils irrigated with high carbonate ground waters in the Punjab area of West Pakistan, and has been extensively used to evaluate the sodium hazard of Punjab ground waters. (SWC 7-gF10)

At Pomona, California, studies involving the salinity balance in young citrus orchards of Arlington Highlands area irrigated with Colorado River water indicate total salinity in the soils continues to be in the low ranges and does not constitute a hazard to citrus. In sprinkler-irrigated soils, the salinity is about at the level where any increase will result in reductions in yield. Salinity in the furrow-irrigated soils is well within the tolerance limits. Soils data indicate that an equilibrium with Colorado River water is reached before the soil becomes sodic.

During 1963, the ratio between calcium plus magnesium and sodium was found to be a better means of expressing the rate and degree of change within the soil profile. This ratio has two advantages, (a) it indicates that sodium becomes predominant when the ratio values are less than 1.0 and, (b) it does not require a knowledge of volume and quality of the irrigation and drainage water for assessing the changes that occur. Since 1957, the start of the project, each soil has shown a decline in the ratio values at the beginning and has levelled off after two or three years of irrigation. In all cases the leveling off point is near or above 1.0. The trends in the ratios of calcium plus magnesium to sodium in the drainage water for the years 1961 to 1963, inclusive, are generally downward and indicate the equilibrium with Colorado River water is being reached in the soil profile. (SWC 7-g1)

D. Water, Soil and Crop Management Systems for Saline and Sodic Soils

At Grand Forks, North Dakota, bare soil-mulch fallow substantially reduced salinity in the root zone of a nonirrigated soil using natural precipitation. Cropping to small grain caused salinity to fluctuate but did not change it greatly; continuous grass, cut for hay, caused soil salinity to increase. One season of fallow reduced salinity in the 6- to 24-inch depth by 45 percent; second and third consecutive seasons of fallow gave additional salt reductions, especially at lower depths. Salinity of the top 6 inches remained relatively unchanged for a period of three years under fallow and small grain but increased slightly under harvested grass. In 1963, the yield of wheat following fallow was 4.5 times that of wheat following barley.

Two years of observations on western North Dakota sodic soils known as solodized-solonetz (Rhoades-Moline series), indicate that permeability is increased, adsorbed sodium reduced, and grass yields increased by adding manure and gypsum. Yields were further increased by deep tillage with the soil amendments. Soil amendments alone were more effective than irrigation alone in both reducing adsorbed sodium and increasing yields. (SWC 7-d1)

Undercutting to lower the surface elevation of saline soils, combined with bordering to hold runoff from a contributing area, resulted in effective salt leaching at Weslaco, Texas. Approximately 80 percent of the soluble salt leached beyond the 6-foot soil depth over a two-year period. Data from two adjacent fields, one level and the other nonlevel, indicate that leveling alone has not been effective in reducing the salt load of nonirrigated soils.

Also at Weslaco, Texas, two specialized surface management practices, a permanent ridge-furrow system and a cotton bur mulch, facilitated leaching by rainfall of soluble salts from the seeding zone for grain sorghum. Seeding beneath the leached furrows gave satisfactory stands of grain sorghum on soils previously too saline for seed germination and seedling establishment. Salt concentration was reduced to a lower level beneath mulched soils than beneath permanent furrows during the same time interval. However, the mulch significantly reduced sorghum seedling establishment by exerting mechanical resistance to seedling emergence. Reseeding with equipment that left a narrow strip of unmulched soil directly above the planted seed until seedling establishment resulted in excellent stands on previously barren, saline soil.

Analysis of soil of the open ditch drainage spoilbanks at Weslaco, Texas, showed that 80 percent contained soluble salt concentrations high enough to give EC_e values greater than 4 mmhos./cm. Therefore, salt concentration should be determined and included in the criteria used to determine if a particular spoilbank should be used in land leveling operations. (SWC 7-e1)

Low producing, saline-sodic, "slick spots" soils in southwestern Idaho and southeastern Oregon represent substantial portions of many irrigation fields. The results of a field trial in Oregon based on small plot studies show that saline-sodic soils containing heavy claypan and nodular hardpan

layers can be effectively reclaimed on a field basis by deep plowing. Water intake rates, water and root penetration on the deep-plowed slick spots remained at moderately high levels through the fourth year after deep plowing. The soluble salts and exchangeable sodium were markedly decreased within three crop years. A field trial on similar soil in Idaho gave similar results. The deep-plowed slick spots produced 90 bu./acre of barley the first year and 32 tons/acre of sugar beets the second year. Yields were not adversely affected by deep plowing on the adjacent nonsaline soils. Gypsum at rates of 8 and 16 tons/acre did not materially affect yields. (SWC 7-f1)

Salinity studies on potato plots in San Jacinto Valley, near Pomona, California, show that low application rates of Colorado River water (1-inch per week for a total of 12 acre-inches in a twelve-week growing season) moved artifically applied salt to a depth of 18 inches. A medium application rate (1.7 inches per week) increased salinity slightly at depths below 18 inches but most of the salts remained in the surface 18 inches. High rates of irrigation application (2.5 inches per week) caused substantial movement of salts into the lower depths of the soil profile. Complete leaching, however, did not occur as most of the salts remained above the 3½-foot depth. The irrigation water was unable to counteract the effects of salinity during the seedling stages of growth, although salinity was substantially decreased by mid-season.

A four-year study of leaching highly saline Gila silt loam and the subsequent growth of plants in the Wellton-Mohawk area of Arizona indicated that at least 3 feet of preplant leaching water are necessary for good crop growth. Such leaching reduced the salinity level of the surface 8 inches of soil almost as much as did 6 feet of water. A smaller amount of preplant leaching (1 foot) actually aggravated the salinity problem in the surface seed-planting zone. Maintaining a high moisture content in the root zone appeared to be important in preventing salt damage to the growing crops, as the wetter irrigation regime resulted in decreased salinity levels and higher yield of both sudangrass and alfalfa. (SWC 7-g1)

E. Leaching Processes.

Using the progressively diluted high-salt water method of reclaiming sodic soils, developed at the U. S. Salinity Laboratory, Riverside, California, a sodic soil near Hemet, California, was reclaimed by leaching with four successive 1:1 dilutions of water having a concentration of 0.6 normal, the cations of which were about 25 percent $Ca^{++} + Mg^{++}$, and 75 percent Na^{+}. A total of 10.2 meters of water were required to accomplish the reclamation in a period of 170 days. Ponding water for 228 days on adjacent plots with either the conventional gypsum amendment method or Colorado River water alone did not reduce the exchangeable sodium below the 15-cm. depth. In the 15-cm. depth the ESP was reduced from 75 to 32 for the conventional gypsum treatment and from 71 to 57 for the Colorado River water alone. The amounts of water entering the soil were 36.0 cm. and 26.9 cm. with average

intake rates of 0.16 and 0.12 cm./day for the gypsum and Colorado River water treatments, respectively. (SWC 7-gF11 and SWC AID-0-1-4)

It was discovered in the leaching studies at Riverside, California, that serious errors were involved in the conventional method of measuring permeability of the soils because of leakage along the boundary between the soil and the permeability container whenever high electrolyte solutions were used. The flocculating effect of high-salt water following a water of low salt concentration resulted in abnormal increases in water passage through the permeameter. By use of dyes it was demonstrated that leakage occurred at the boundary between the soil and the container. Apparently, this leakage resulted from shrinkage of the entire soil mass and the associated recession of soil particles away from the permeameter walls. A new type of permeameter has been designed and tested which allows measurements of the permeability of the central portion of the soil column. Measurements on two soils with this new equipment have shown that in some cases, the boundary leakage effect caused as much as a fourfold variation in measured permeability values.

The ability to diagnose permeability problems is simplified considerably by this new measurement technique. The study thus far has yielded an insight into the major factors which affect water movement rates in soils, and substantial progress has been made toward developing general empirical equations which are based on measurable properties of the soil and water. For judging irrigability and the potential of new irrigation developments, as well as for delineating and assessing soil permeability problems, the usefulness of equations that will allow the prediction of the permeability of soils to the passage of water is evident. (SWC 7-gF11 and SWC 7-gF7)

Salt-leaching plots were established at Painter and Norfolk, Virginia, and Currituck, North Carolina, to evaluate the effect of winter rainfall on leaching accumulated salinity out of the soil profile. Winter rainfall is generally adequate for leaching accumulated salts out of a 3-foot profile in these areas. During the spring and summer of 1963, however, the weather was extremely dry and some salt movement up to the surface was noted at Norfolk and Painter, Virginia. This accumulation, though not in excess of 2 mmhos./cm. in the saturation extract of the surface soil, was largely responsible for a reduction in yield of beans on the plots at Norfolk, Virginia. (SWC 7-a1)

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AREA 8: WATER AND WIND EROSION CONTROL PRINCIPLES, PRACTICES, SYSTEMS AND PREDICTION METHODS

Problem. Erosion from farm fields in the humid and semiarid areas is the major source of silt which pollutes the streams of these areas. Control of erosion is a major requirement of watershed protection and development programs.

Water and/or wind erosion control continues to be a problem in all areas having cropping systems that require plowing, tilling, and planting. In both irrigated and dryland farming areas, wind erosion is a problem. Sand blasting has caused serious damage to young plants in the sandy eastern seaboard vegetable-producing areas. Careless application of irrigation water has resulted in serious erosion. The Kerr Report No. 28 emphasizes that full understanding of fundamental erosion and sedimentation processes is a prerequisite for the planning and execution of successful programs for water resource development and utilization. SCS' Soil and Water Conservation Research Needs reports continue to stress the urgency of erosion research.

As new farming practices come into use, erosion and erosion control methods must be made compatible with the new farming systems for successful use of the Nation's farmlands. The wide variations possible under factors of soil, climate, crops, and management create highly complex relationships and make it imperative to determine basic principles governing the movement and loss of soil and water. Improved control measures and prediction equations developed from these principles will provide a scientific basis for application of control practices and structures and for classification of areas of potential damage for deciding land use recommendations and the retirement of critical areas to permanent vegetation.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of water and wind erosion utilizing soil physicists, soil scientists, analytical statisticians, and agricultural engineers. Basic principles and mechanics of water erosion are under study in New Hampshire, Georgia, Indiana, Minnesota, Illinois, South Dakota, and Washington; and of wind erosion in Kansas. Studies of soil physical and chemical characteristics in relation to the prediction of soil erodibility are underway in Maine, Georgia, Kansas, Indiana, and Iowa. Erosion tolerance and soil renewal are under study in Kansas and New York. Studies to determine interrelations of climate, soil, topography, cover, and management to runoff and erosion are underway in New York, Maine, Georgia, Mississippi, Indiana, Missouri, Iowa, Minnesota, Wisconsin, South Dakota, Nebraska, Kansas, Oklahoma, Texas, Oregon, Idaho and Washington; and to wind erosion in Kansas, Texas, Georgia, Montana,

and New Mexico. Studies to develop improved methods for predicting water erosion are underway in Indiana, and for predicting wind erosion, in Kansas. The development of practices, structures, and systems for modification of wind, water, and soil movement is underway in New Hampshire, New York, Virginia, Georgia, Mississippi, Iowa, Missouri, Minnesota, Wisconsin, Oklahoma, Texas, Idaho, Oregon, Washington, and Kansas. The scientific and engineering effort in this area totals 34.0 professional man-years per year with 10.5 devoted to basic principles and mechanics of water and wind erosion; 15.5 to interrelations of climate, soil topography, cover, and management to wind and water erosion; 1.6 to equations for predicting soil and water losses; and 6.4 to practices, structures, and systems for modification of wind, water and soil movement.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are engaged in fundamental and applied studies of the basic principles and mechanics of water and wind erosion. These studies seek better understanding of the magnitude of forces involved in wind movement across soil surfaces and in the impact of falling raindrops. The dissipation of this energy in terms of soil compaction, detachment of particles and movement of soil is being investigated. Studies are under way on effects of soil physical and chemical properties, plant cover, tillage, surface roughness and other related factors on the nature and extent of water and wind erosion.

Interrelationships of factors influencing the occurrence and extent of erosion are being studied. Erosion losses vary with differences in climate, soil properties, topography, tillage and management. Field and laboratory studies are in progress seeking to evaluate the effects of individual factors and to determine interrelationships between various combinations. Research is directed toward evaluation of tillage practices, surface mulching and crop rotation practices which influence the physical and moisture properties of the soil. Terracing, strip cropping and contouring are evaluated individually and in combination for effectiveness in erosion control and for suitability under modern farming procedures.

The total research effort on water and wind erosion problems at the State experiment stations is 11.1 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Basic Principles and Mechanics of Wind and Water Erosion

1. Mechanics of wind and water erosion. Measurements of wind drag over different agricultural fields, made at Manhattan, Kansas, as a part of continuing investigations of the mechanics of wind erosion, showed that surface drag for a given wind varies widely depending on the roughness of

the field surface. Surface drag cannot be equated with computed drag velocity unless a drag coefficient is known. The coefficient was found to vary with maximum height of surface projection, the zero velocity-height intersect, and the velocity gradient displacement. This information has been needed to determine whether surface drag can be computed from theoretical equations developed from wind velocity-height relationships. (SWC 8-e1)

Waterdrop splash studies at Morris, Minnesota, showed that greater surface roughness decreased the size of the splash pattern, but its influence decreased as surface water depth increased. Increased soil softness had little effect on splash width or height. However, it decreased the outward direction of splash and thus had an effect similar to increased water depth.

In a laboratory study at Lafayette, Indiana, of the influence of slope steepness, slope length and soil particle size on splash and runoff erosion using a simulated noncohesive soil, runoff erosion increased as slope steepness increased, as slope length increased, and as particle size decreased. Combining rainfall with surface flow increased erosion of the smaller particles, but decreased erosion of the larger particles. Splash erosion from the soil bed was very minor relative to runoff erosion. The quantity of splash increased with decreasing runoff rate where rilling was not great, and with increasing runoff rate after significant rilling occurred. Soil movement by raindrop splash increased downslope erosion more by supplying sediment into the runoff than by splash movement alone.

Strong evidence was found of critical slope steepnesses and slope lengths below which no appreciable erosion occurred. Addition of critical values to the power equations greatly improved their fit to the data. Furthermore, much of the highly significant interaction between slope length and slope steepness which occurred in a multiple regression analysis was explained by addition of the critical values. These results corresponded closely with sediment transport relationships. (SWC 8-c1)

Tests in an open channel flume developed at Watkinsville, Georgia, show that by use of a specific type of fiber board a desired tension can be placed on a body of soil to create internal drainage under water flowing on the soil surface. Samples have been collected for five typical Piedmont soils and tests are in progress to determine the critical tractive force for these soils. (SWC 8-b2)

2. Soil erodibility. At Manhattan, Kansas, additional experiments to evaluate the effect of soil surface roughness on erodibility of soil by wind confirm that wind erosion of soil does not decrease proportionally with surface roughness. Erodibility decreased as surface roughness increased until ridges were 2 to 4 inches high, depending on wind velocity and soil cloddiness. It then increased with ridges higher than 2 to 4 inches. This is important information for use in the wind erosion equation to evaluate any degree of ground roughness. (SWC 8-e1)

Soil-erodibility measurements under simulated rainfall on 32 soils in Indiana and adjoining States have shown a wide range in the erodibilities of different soils, even within standard textural classes. Variables having the greatest influence on soil erodibility were: percent silt, percent sand, suspension percentage, interactions of these three with each other and with organic matter content, aggregation index, and dispersion ratio. These primary and interaction effects explained 90 percent of the variation in the basic erodibility of the soils studied. Soil erodibility generally increased with an increase in silt content and decreased with increase in sand content; but organic matter, soil aggregation, and other variables were found to greatly modify soil erodibility within textural classes.

At Ames, Iowa, in a study of the relationship of soil properties to erodibility using samples from five soils representing a range in texture, total soil eroded in 90 minutes of rain at 2.7 inches per hour was in the direct order of increasing proportions of fine separates: silty clay>silty clay loam>silt loam>loam>loamy sand. Soil loss rates were in reverse order of final infiltration rates. However, interaction of properties that affect infiltration rate and permeability with those that resist dispersion and transport was found to be very important. The loamy fine sand (11% clay) was essentially noncohesive and detachability was high. Both in amount of splash and in soil loss per unit of runoff the loamy fine sand was highest of the five texture classes tested. But it required nearly twice as much rainfall energy to start runoff, the infiltration rate remained higher, and total soil loss in 90 minutes was much lower than for any of the other soils. Soil loss peaked at a high rate shortly after runoff started and then levelled off at essentially the same rate as that of the loam and silt loam. (SWC 8-c2)

At Watkinsville, Georgia, using data secured with the field plot rainfall simulator on 35 sites of 13 soil types in Georgia and South Carolina with soil textural classes ranging from loamy sand, deep phase, to silt loam, a regression analysis of 26 independent variables showed that very complex relationships exist between rainfall, runoff, soil erodibility, and soil properties. Eighty percent of the variation in runoff was explained by the silt content, clay content, and bulk density of the soil. Nine additional variables, including the separate sand fractions (clay/sand) plus silt and amount of rainfall, increased the correlation with runoff to 93 percent. Twenty variables were required to explain 74 percent of the variation in soil loss per unit of rainfall erosion potential (EI) when the measured losses were adjusted to the standard of fallow soil on 9 percent slope with a length of 72.6 feet. There was no direct relation between soil loss per EI unit and soil textural class or soil series.

A log of soil losses during rain simulator storms applied at 2.5 inches per hour for two hours showed that during the early part of a storm the silt and clay content of washoff was high and sand was low. As the storm progressed, the sand, silt, and clay in the washoff approached that of the original surface soil. Although, in general, the silt and clay were higher and sand was lower in the total washoff than in the original soil, often the

very coarse- and coarse-sand fractions in the washoff were higher than in the original soil. (SWC 8-b1)

3. Erosion tolerance and soil renewal. At Manhattan, Kansas, following the development of mathematical expressions to define erosion tolerance and related concepts, a procedure to establish an erosion tolerance standard was developed. The procedure is based on five minimum assumptions and three decisions. The assumptions are: (1) Soil is to be permanently maintained or improved; (2) soil properties are subjected to both erosion and renewal; (3) all kinds of erosion and renewal are involved; (4) fractional using up of reserves is tolerable; and (5) economic influences determine choices within tolerance. It is necessary to decide: (1) What soil properties are being worn away by erosion; (2) how much of these properties should be saved for the future; and (3) the rate of soil property renewal. Soundness of the decisions, which depend on public policy and technical facts or estimates, determines precision of the established tolerances. (SWC 8-e1 and SWC 8-e2)

Measurements of dust deposition rates from the atmosphere at Manhattan and Hays, Kansas, have shown that the quantity of material deposited may well be a significant factor in soil renewal. The influx has averaged slightly over 1 pound per acre per day during a time when there were no actual dust storms. Texture, color, and mineralogy have varied from month to month between locations. Absence of montmorillonite and other index minerals shows the source of dust to date has not been the "dust bowl" area. Establishment of a network of eight additional cooperative stations for dust trapping at other locations in the United States is in progress. (SWC 8-e1)

In New York, severely eroded land (ex-fallow) and noneroded land (ex-meadow) were placed in a program of good soil management in 1942 to study the ability of a badly eroded soil to recover its productivity. For the first few years, corn yields from the eroded plots were approximately 50 percent of those from the noneroded. Since 1952, the differences in yields averaged about 10 percent. In 1962, corn yields from the noneroded plot were only 6 percent greater and in 1963 yields from the eroded plots slightly exceeded those from the noneroded area. (SWC 8-a1)

B. Interrelations of Climate, Soil, Topography, Cover, and Management to Water Runoff and Erosion and Wind Erosion

1. Water runoff and erosion. Interaction effects of slope, row direction and vegetation on soil erosion were investigated in a three-year study at Morris, Minnesota, under both corn and oats. Even within the 4 to 10 percent slope range included in this study, the erosion-reducing effectiveness of across-slope tillage was significantly influenced by slope steepness. The practice was most effective on the 7 percent slope and during the establishment period for corn. The nearly complete ground cover provided by oats in crop stages 3 and 4 largely masked the effects of both slope and row direction on the 13- by 75-foot plots. The slope-soil loss relationship was

little affected by stage of corn growth when rows were up-and-down-slope. Overall, the across-slope plots averaged 27 percent as much soil loss as the up-and-down-slope plots.

At Morris, Minnesota, in the first year of a study of the relationship of shape of slope to runoff and soil loss, simulated rainstorms were applied in crop stages 1, 2 and 3 on first-year fallow, oats, and corn. Convex slopes (steepening toward the lower end) averaged 45 percent more soil loss and 37 percent more runoff than equivalent uniform slopes. These relationships did not differ greatly for the three types of cover. The tests will be repeated in 1964 on second-year corn, oats and fallow. (SWC 8-c2)

For the fourth consecutive year, at Presque Isle, Maine, on a Caribou silt loam, rock removal increased soil loss and runoff under continuous potatoes. Crushing and returning rocks decreased losses only slightly. Treatment differences between years depend upon the amount, intensity and distribution of rainfall. Soil loss and runoff from continuous potatoes were 3.83 tons and 6.68 inches per acre, respectively, whereas for potatoes grown in an oats and sod rotation, per acre losses of only 2.07 tons and 4.12 inches were obtained. Although potato yields were slightly better when grown in rotation than when grown continuously, there were no significant differences in potato yields as a result of the rock removal treatments. Soil compaction due to tractor traffic on these plots reduced potato yields 8 percent. (SWC 8-a1)

Flax, after establishment, provided good protection against erosive rainstorms applied artifically at Madison, South Dakota. Total soil loss from storms applied at three successive stages of growth was about half that from corn or sorghum. In cropstage 3, the flax provided about 95 percent canopy cover, antecedent soil moisture was about 10 percent less than under corn and sorghum, and erosion losses were very low.

Rainulator tests at Lafayette, Indiana, showed that excess tillage of plowed meadowland resulted in little carryover of the erosion-reducing benefits from meadow sod beyond the first year after plowing. Various lengths of fallow following good quality grass and legume meadow were compared after all test areas had been disked five times during a two-month period following turn plowing. Erosion losses from first, second and third years of fallow after meadow were 54, 96, and 99 percent, respectively, of the loss from fourth-year fallow. Aggregation indices were 0.57, 0.20, 0.19, and 0.15, respectively, for the four successive years of fallow. Other studies, with less tillage, have shown substantially greater carryover of sod effects into the second corn year. (SWC 8-c2)

Of three methods of corn tillage (conventional, zero tillage, and wheel-track planting) evaluated on a Honeoye soil in New York, results indicated that both soil loss and runoff during the growing season were least for wheel-track planting. The conventional treatment allowed a maximum soil

loss of 4.3 tons per acre as compared with 2.0 tons per acre for zero tillage and 0.4 ton per acre for wheel-track planting. An excessive rate storm of 1.3 inches caused 80 percent of the soil loss during the growing season. (SWC 8-a1)

At Lafayette, Indiana, a five-year study completed in 1963 showed minimum tillage for corn to be highly effective in increasing infiltration and reducing soil erosion. The effectiveness of minimum tillage was greatest when the corn followed meadow sod and decreased substantially with successive years of corn, even when heavy corn residues were turned under. Soil losses from first-, third- and fifth-year corn after meadow were 44, 34 and 27 percent less, respectively, than from corn on conventional seedbed. Corresponding increases in infiltration were 25, 25, and 21 percent, respectively. Soil aggregation, under minimum tillage as compared with conventional tillage, was not appreciably improved over the five-year period. Destruction of surface crusts by secondary cultivation reduced soil and water losses and increased corn yields in each of the three test years during the five-year study period. Minor differences in minimum tillage methods, such as smoothing after plowing, plow plant, or wheel-track plant, had little effect on the relative erosion-control benefits from the practice.

In rainulator tests immediately after corn planting on 12- by 35-foot plots on 8 percent slope, the erosion-reducing benefits of minimum tillage were substantially greater when tillage operations were across-slope than when they were up-and-down-slope. Soil loss from minimum tillage was 13 percent of that from conventional seedbed when farming was across-slope and 39 percent when farming was up-and-down-slope. The increase in effectiveness of contouring under minimum tillage was reflected both in reduced runoff and in reduced sediment content of the runoff.

At LaCrosse, Wisconsin, minimum tillage for second- and third-year corn was much more effective when prior-year crop residues were plowed under at planting time than when they were removed. In a three-year study on 10 percent slope, erosion loss from plots with residues turned under each year averaged 1.4 tons per acre, while that from well-fertilized plots from which residues had been removed before seedbed preparation with a field cultivator averaged 7.5 tons. Runoff averaged 0.4 and 1.4 inches, respectively. (SWC 8-c2)

Mulches to protect newly established grass seedlings are often used on embankments and other denuded areas. Studies at Lincoln, Nebraska, have shown that the same amounts of prairie hay mulch applied loose or anchored with a disk packer provided equal protection against water erosion. Cross-slope operation provided better protection than up-and-down-slope operation. Asphalt emulsion applied both to bare soil or to "anchor" 1,000 pounds of prairie hay mulch provided highly effective protection against water erosion. Wood chips were less effective than either straw or hay; one ton of hay provided about the same soil protection as five tons of wood chips per acre. (SWC 8-d1)

Results of infiltration, runoff, and erosion studies with the double-tower sprinkling infiltrometer at Cherokee, Oklahoma, showed that infiltration rates on second-year wheat following alfalfa with 5,600 pounds per acre of straw cover were about two times greater than on second-year wheat following weeping lovegrass with 2,500 pounds of cover per acre. (SWC 8-e2)

At Pullman, Washington, when soil was frozen 18-24 inches deep, runoff and erosion were not affected by either cropping or fertilization treatments. Apparently, the extremely low permeability of frozen soil masked the effectiveness of treatments. On February 3 and 4, 1963, 1.96 inches of runoff were measured from a total precipitation of 2.31 inches of snow and rain during this period. At St. Anthony, Idaho, on February 1 and 2, 1963, 3.83 inches of runoff occurred from plots planted to winter wheat and 4.60 inches from those in stubble. The remainder of the snow on the stubble area melted on February 11, producing an additional 0.31 inch of runoff. These measurements illustrate the potential for improvement in moisture conservation in this area where the average annual precipitation is 13.19 inches.

Initial surface roughness measurements on several tillage treatments before the seeding of winter wheat at Pendleton, Oregon, show that the areas would hold at least 1.85 inches of water in the surface depressions. Vertical mulch trenches were still opening up and taking surface water four to five years after their construction. (SWC 8-f1)

2. Wind erosion. At Garden City and Colby, Kansas, continuing evaluation of stubble mulch tillage machinery performance with emphasis on determining the tillage machines' role in conserving residue for wind erosion control has shown that undercutting stubble immediately after harvest does not necessarily reduce residues, and that weed growth occurring before winter and the lifting of buried residue by subsurface sweeps during the first spring tillage can completely offset undercutting and winter weathering losses. Significant information on effects of tillage during regular summer-fallow cultivation included: (1) Tillage sequences using subsurface sweeps consistently retain substantially more residue on the surface than do those sequences using disks; (2) far better weed control is obtained with sequences using disks; (3) there is little relationship between kind of tillage machine and soil cloddiness produced; (4) higher wheat yields were obtained with tillage sequences using disks than with those using subsurface sweeps during two out of four years; (5) no definite evidence to confirm the belief that there is a climatic effect and that tillage machines conserve less residue in southwestern Kansas than they do in northwestern Nebraska.

Results reported from Bushland, Texas, of field studies at Hardesty, Oklahoma, indicate the best approach found so far for stabilizing active sand dunes at a minimum cost is to employ practices which encourage growth and cover of existing plant species. This is best accomplished by excluding livestock and by fertilization of native plants. Imbedding grass seeds in

pellets of clay soil before planting, growing broomcorn and amber cane mulches in place, and applying hay mulches all either failed or were too expensive.

At University Park, New Mexico, studies to determine the effect of different methods of soil stabilization on establishment of grass have provided some information relative to erosion control. Treatments included spraying with asphalt emulsion and petroleum resin solidly and in strips on both furrows and level land. Lack of rainfall prevented obtaining a good stand of black grama grass; however, there was no evidence of a treatment effect on the number of volunteer plants. The petroleum resin provided a more stable film against blowing sand for a longer period of time than did the asphalt. Strip applications on furrows had more exposed edges and therefore deteriorated most rapidly. Solid-sprayed level plots deteriorated least but did show some lessened effectiveness due to cracking and rodent damage. Less erosion occurred on all sprayed plots than on nonsprayed. (SWC 8-e1)

Observations of wind erosion in the Coastal Plain of South Carolina during the early spring months showed there were eight severe windstorms in 1963. Small crops were damaged; soil was blown from the field; and deposition occurred along fence rows, on roadbanks, and at field borders. Analyses of soil samples showed the susceptibility of soils to blowing ranged from quite low for Lakeland sand to very high for Eustis loamy fine sand. The estimated average annual losses ranged from 9 to 31 tons per acre, respectively, for these soils, indicating a need for protective measures in this area. (SWC 8-b1)

3. Rainfall simulators. A rotating boom rainfall simulator has been developed at Lincoln, Nebraska, that overcomes many objections inherent in previous applicators. It is trailer-mounted and can be easily moved from one set of plots to another; drop sizes and terminal velocity of drops approach those of natural rainfall; it is capable of applying uniform, reproducible storms of 2.5 and 5.0 inches per hour intensity; and it can operate with minimum interference from winds up to 15 mph. Use of this equipment offers flexibility in scheduling and conducting experiments requiring runoff and erosion data. (SWC 8-d1)

C. Equations for Predicting Soil and Water Losses

1. Water runoff and erosion. Further refinement of the water-erosion prediction equation is being made by continuing studies of equation factors and factor interactions at Lafayette, Indiana, using data from the current rainfall simulator and natural rain plots.

Progress has been made in relating soil physical and chemical properties to the soil erodibility factor (Section A-2). Since these properties can be directly measured in the field or laboratory, the feasibility of a multiple regression equation that will evaluate the soil-erodibility factor for the

various specific soils without erosion measurements is strongly indicated. Data from replicated fallow plots under natural rain have provided values of the soil erodibility factor for each of eight additional benchmark soils.

Recent analyses at Lafayette, Indiana, have indicated that the relation of slope length and steepness to the rate of soil erosion has been changed by the developments of improved soil, crop and residue management practices. These improved practices appear to be more effective on the shorter and flatter than on the longer and steeper slopes. In ten years of erosion measurements from corn at a very high level of management on Mexico silt loam with 3 percent slope, a 420-foot slope length lost 4.5 times as much soil per unit area as an adjacent 90-foot slope length. The expected ratio under earlier management levels would have been about 2.2. On moderately eroded Shelby loam with a long history of intensive cropping and poor residue management, soil loss from corn varied as the 0.4 power of slope length; on an adjacent area plowed out of virgin sod it varied as the 0.9 power of slope length. Under a truck crop system with rye winter cover and moderate fertility at Marlboro, New Jersey, doubling a 70-foot slope length increased soil loss by one-third. When fertility and residue content of the soil were improved by the addition of 20 tons of manure annually, the same increase in slope length doubled soil loss because of the decreased loss on the shorter slope. Both at LaCrosse, Wisconsin, and at Marcellus, New York, the observed value of the slope-length exponent was more than twice as great on 18 percent slope as on slopes in the 5 to 9 percent range.

Studies at LaCrosse, Wisconsin, have shown that cropping-management factor values derived for high level management on moderate slopes underestimate erosion losses on slopes steeper than about 10 percent. In five years of measurement on Fayette silt loam managed at the conventional level for the 1930's, plots on 13 percent slope lost 3.4 times as much soil as those on 8 percent slope. Under what would be considered very high management level today, the same 13 percent slope lost 8.7 times as much soil as the 8 percent slope. High-quality meadow sod turned under before contoured corn in 1960 essentially eliminated erosion loss from 3 percent and 8 percent while a nearby 18 percent slope with similar treatment and corn yields lost 10 tons of soil per acre. These findings have particular application in the loess area of western Iowa, where the length-steepness interaction and the interactions of both length and steepness with management level all combine to increase the normal spread between plot and field erosion rates. (SWC 8-c3)

At Manhattan, Kansas, significant advances in improvement and application of the wind erosion equation were as follows: (1) a field evaluation in New Jersey confirmed that the equation is a useful tool in establishing conservation-cropping systems for wind erosion control in vegetable-growing areas outside the Great Plains; (2) inclusion of factors for determining wind erosion on tops and windward slopes of knolls and hills; (3) inclusion of new information on effects of soil surface roughness.

At Manhattan, Kansas, analyses of weather records were continued and the wind erosion climatic factor was computed for areas in the United States east and west of the Great Plains. Maps, indicating the wind erosion factor by small increments, were prepared. States in the eastern half of the United States fall in a "very low" to "low" wind erosion susceptibility category while those in the western half range from a "very low" along the Pacific Coast to a "very high" susceptibility in southern California, Arizona, Nevada, and Utah. The wind erosion climatic factor for the Great Plains was computed in 1961. This year's information will be useful in extending application of the wind erosion equation to areas outside the Great Plains. (SWC 8-e1)

D. Practices, Structures and Systems for Modification of Wind, Water and Soil Movement

1. Contour and terrace systems for rainfall runoff and erosion control. Contouring effectively controlled both runoff and soil losses in 1963 on silt loam soils with 5 percent slope, steepness and terrace interval length at Holly Springs, Mississippi. Runoff was 0.73, 3.95, and 6.17 inches from corn with closed-end contour rows 13 feet long, rows 150 feet long, on formed plots with controlled row grades of not more than 0.4 foot per 100 feet of row length, and rows 150 feet long with uncontrolled grades and soil of low fertility, respectively. Soil losses were 0.14, 0.77, and 7.15 tons per acre, respectively, from these conditions. The graded rows 150 feet long represent parallel-terraced field conditions, and suggest the superiority of controlled row grades on formed land, although losses may be considerably higher than those measured on narrow runoff plots with perfect contouring. (SWC 8-b1)

Farm machinery operating efficiency should be higher in fields with parallel terraces as compared with conventional terraces. Detail measurements in a Piedmont field at Watkinsville, Georgia, with three conventional terraces showed the average row lengths were 209, 242, and 361 feet, respectively, for the separate intervals. Calculated machine capacity at an operating speed of 2.5 mph. was 1.33, 1.40, and 1.56 acres per hour and at 4.5 mph., 1.89, 2.02, and 2.38 acres per hour, respectively. Turning time was 34 and 48 percent of the total time for speeds of 2.5 and 4.5 mph., respectively, in the interval with rows 209 feet long. With the longer 361-foot rows, the turning time was reduced to 23 and 35 percent of the total time at the two speeds. Similar data will be secured from parallel terraces where all the rows are long rows. Basic land forming work for the parallel terrace area was completed at a cost of $21 per acre. The land capability of the field prior to land forming was 75 percent Class II_e and 25 percent Class III_e. After land forming, the percentages were 60 for Class II_e and 40 for Class III_e, the increase in III_e being due to more exposed subsoil on the field. (SWC 8-b2)

At Castana, Iowa, the influence of terrace spacing and type of tillage on the performance of level-terrace systems is being studied on steep, deep-loess (Ida) soils. An early June period of frequent, high-intensity rainstorms caused no overtopping of terraces, although they had lost more than 1 inch of their 2-inch design capacity. Soil loss during 1963 from the listed corn was only half that from surface-planted corn. Runoff was also decreased by listing. During the four-year period of this study, listing was less effective at a 72-foot terrace spacing than at a 125-foot spacing, presumably because terrace construction increased the land slope of the narrow spacing more than on the wide spacing. (SWC 8-c4)

At Cherokee, Oklahoma, the erosion occurring in terrace channels was determined from measurements made on four pairs of 200-foot level terraces, one terrace in each pair with concrete channel and the other with normal earth channel. This first year's results showed that very small amounts of runoff and erosion were contributed by the channels. In three out of four of the pairs, runoff and erosion amounts as measured at the discharge ends were practically identical. (SWC 8-e2)

2. Deep profile modifications for soil and water conservation. Loosening and mixing the profiles of Freeman soil at Rockford, Washington, continued to improve the storage of soil moisture and to increase crop yields. Soil mixed 4 feet deep provided 1.5 inches more water and increased alfalfa yield 1.3 tons over that mixed 6-8 inches deep. Increased use of soil moisture by winter wheat was also observed with the deep plowing treatment. Total depletion from the 9- to 36-inch layer during the growing season was 6.2 inches on the deep-plowed and 4.2 inches on the conventionally plowed land. Most of this additional moisture came from the 24- to 36-inch depth. At high fertility levels, wheat yielded 65 bushels on the deep-plowed land in contrast to 45 bushels on that shallow plowed. The 48-inch mixing increased the available moisture and decreased the heaving of alfalfa. Heaving of seedling averaged 1.8 cm. on the conventionally plowed plots in contrast to only 0.3 cm. on the plots mixed 4 feet deep. There seems to be no measurable increase of bulk density on the deep-mixed plots within the last two years, particularly in the 12- to 48-inch depths.

At Pendleton, Oregon, fields with intermittent claypan areas plowed in 1961 to a depth of 36 inches have since shown a slow increase in bulk density. Surface elevation is now 0.11 to 0.18 foot above that before plowing. Weeds were generally less of a problem on the deep-plowed land. Land plowed 36 inches deep produced slightly more wheat than that plowed at the normal depth but the green pea yield was slightly lower. (SWC 8-f1)

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AREA 9: MOISTURE CONSERVATION FOR THE EFFICIENT AND EFFECTIVE USE OF PRECIPITATION ON CROPS AND RANGELANDS

Problem. One of agriculture's major plagues in the United States is recurring drought. In 1963, the U. S. Department of Agriculture declared over 600 counties in some 18 states emergency areas because of drought. Inadequate moisture is the main factor limiting plant growth on cultivated land and rangelands in the Great Plains. Tree ring studies conducted in Nebraska show that 269 of the past 748 years were sufficiently dry to adversely influence crop production. Weather records at several locations in the Plains show that precipitation was below average 50 percent of the time. In most parts of the Great Plains, the frequency and amount of precipitation have significant social and economic consequences. If some means of reducing the large loss of water by evaporation and transpiration were available, the precipitation received would be more than adequate to support good plant growth and still provide sufficient water for other uses. The amount of moisture needed for actual plant metabolism is only a small part of that actually transpired by the plant. The amount of water used for transpiration is, in turn, usually less than the amount lost directly from the soil by evaporation.

The research in this area is directed toward the development of methods for increasing the infiltration of water into the soil profile, decreasing the evaporation of soil moisture, and controlling transpiration by physical and chemical means.

USDA AND COOPERATIVE PROGRAM

The Division conducts both basic and applied research and development in the area of moisture conservation, utilizing soil physicists, soil chemists, soil microbiologists, and agricultural engineers. Research evaluating the factors associated with influencing moisture storage is being studied at Bushland, Big Spring, Temple, and Weslaco, Texas; Pendleton, Oregon; St. Anthony, Idaho; Riverside, California; Morris, Minnesota; Sidney and Bozeman, Montana; Mandan, North Dakota; and Akron, Colorado. Studies to determine the factors affecting the loss of water by evaporation are being done at Fort Collins and Akron, Colorado; Mandan, North Dakota; Riverside, California; and Big Spring and Weslaco, Texas. Factors influencing the use of moisture by crops are being studied at Mandan, North Dakota; Fort Collins and Akron, Colorado; Pendleton, Oregon; Riverside, California; Big Spring, Weslaco, and Temple, Texas; and Manhattan, Kansas. At all locations, the work is done cooperatively with the respective state experiment stations.

The Federal scientific effort devoted to research in these areas totals 17.0 man-years. Of this total, 8.0 are devoted to factors influencing moisture storage; 7.0 to factors affecting the loss of water by evaporation; and 2.0 to factors influencing the use of moisture by crops.

PROGRAM OF STATE EXPERIMENT STATIONS

The State experiment stations are engaged in a substantial research effort directed toward better description and understanding of the principles involved in the movement of water and gases into, through and from soils. Studies are in progress in infiltration rates in relation to soil physical properties, vegetative cover, tillage, rate of water application and other factors. Water movement is related to gradients created by adsorptive and evaporative forces. Studies concern energy considerations and mathematical description of forces involved in water movement under both saturated and unsaturated conditions in the soil. Western regional research project W-68 and a North Central project NC-40 are concerned with aspects of water movement into and through soils.

Other research is concerned with factors relating to vapor movement of water in relation to soil and plant surfaces. Vapor losses, either as evaporation or transpiration account for a high percentage of the water loss from many agricultural areas. Studies are under way on overall relationships of climatic factors to vapor loss. The work includes measurement and evaluation of solar energy supply and dissipation in heating soil, air and vegetation and in vaporization of water.

Work is in progress on development of tillage and management practices for increasing moisture holding capacity of the soil. Possibilities are being explored for reducing vapor losses through manipulation of moisture at the soil surface, and through variations in plant spacing, density and orientation.

The total research effort at State experiment stations on moisture conservation problems is 29.9 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Factors Influencing Moisture Storage

1. Tillage. Data from Bushland, Texas, have provided some important information on the influence of stubble mulch farming over a 21-year period on the yield of wheat. The average yield of wheat on fallow for the period (1942-1963) was 15.3 and 12.9 bushels per acre for plots with and without a stubble mulch residue, respectively, as compared with average continuous wheat yields of 10.0 and 9.1 bushels for the same treatments. In this area,

stubble mulch farming is one of the simplest and most effective management practices for protecting the land from water and wind erosion. (SWC 9-e1)

Field experiments near Newdale, Idaho, show that on the coarser-textured soils, post-harvest chiseling or rotary subsoiling did not increase the amount of moisture stored in the soil the following spring. Neither did these tillage practices significantly affect wheat yields. On finer-textured soils in the same area, however, post-harvest tillage increased both the moisture stored in the profile and wheat yields. (SWC 9-f1)

In 1963 at St. Anthony, Idaho, the date of initial plowing of summer-fallow did not affect the moisture stored or the yields of wheat. Averages for a 6-year period, however, indicate that early plowing (early May) resulted in the storage of an additional inch of available moisture at the end of the fallow season when compared with the late plowing (mid-June). These data are useful to farmers in timing their tillage and seeding operations for maximum moisture efficiency. (SWC 9-f1)

2. Frozen soil. Studies conducted on land that had been in corn at Morris, Minnesota, showed that precipitation in the autumn was much more efficient in recharging the soil profile than precipitation during the winter months. During the period from mid-September to December 1, 1963, the average soil moisture recharge at five sites on Barnes-Aastad, and Kranzburg-Moody soils in western Minnesota and eastern South Dakota was 3.42 inches or 75 percent of the precipitation that fell. In contrast, soil moisture recharge during the winter months (December 1 to mid-April) was 29 percent of the precipitation on Barnes-Aastad soils, 22 percent on Kranzburg-Moody soils, and 25 percent on the Fargo-Bearden soils. If additional moisture can be stored in the soil profile, increased corn yields can be expected. (SWC 9-c1)

At Morris, Minnesota, the management of crop residues had a material influence on soil moisture recharge. During the fall and winter months, the recharge was greatest on land in corn stalks followed by standing alfalfa and fallow. (SWC 9-c1)

At Sidney, Montana, the soil moisture recharge on chemical fallow at the beginning of the second winter period was greater than that on conventional fallow. By the next spring, however, the differences had disappeared because of the increased infiltration from snowmelt on dry frozen soils in the conventional fallow as compared with the low infiltration in wet frozen soils on the chemical fallow. The wind erosion protection was better on the chemical fallow than on conventional stubble-mulch fallow. (SWC 9-d1)

3. Seeding date. Results of a 6-year field study conducted near St. Anthony, Idaho, show that seeding wheat in mid-August results in 1.5 inches less stored soil moisture in late October than when wheat was seeded in mid-September. Only part of this moisture loss was replenished by winter precipitation. By mid-May, the stored soil moisture under the late-seeded

plots was 0.7 inch more than under the early-seeded plots. Wheat yields on the late-seeded plots were 4 bushels per acre more than on the early-seeded plots. (SWC 9-f1)

4. Surface residue. In the Great Plains, several field experiments have been conducted to study the moisture conserved during the summer fallow period by stubble mulch tillage. At Akron, Colorado, the stored soil moisture at seeding time was 2 and 4 inches for the plots that had 1,500 and 6,000 pounds of residue, respectively. At North Platte, Nebraska, the stored soil moisture under the mulched treatments was 1.7 inches higher than under bare fallow. The stored soil moisture in the surface 6 inches of soil at Bozeman, Montana, was higher under barley stubble than under those plots that had been tilled. The total water in the 4-foot profile, however, was the same at all of the locations under all of the systems studied. (SWC 9-d1)

In these studies, soils in bare plots dried more rapidly and to a lower moisture content than those which had a surface residue. This time lag in moisture loss under the stubble residue has important implications for the plant environment. (SWC 9-d1)

5. Landforming. In the Plains States, conservation benches continue to show promise as a practical means of conserving water. At Akron, Colorado, yields of continuous grain sorghum were 34 bushels per acre on the conservation benches compared with 31 bushels per acre on a crop-fallow system. In these studies, the benches were 100 feet wide with contributing slopes up to 300 feet wide. (SWC 9-d1)

Results at Akron and Fort Collins, Colorado, and at Mandan, North Dakota, show that the most efficient size for the level bench and contributing area has not been determined. For example, at Akron, Colorado, grain sorghum yields on the half of the bench adjacent to the contributing area were 42 bushels per acre as compared with 25 bushels per acre on the other half of the bench. (SWC 9-d1)

At Akron, Colorado, water lost by runoff is being diverted into several level "pans" constructed in existing natural drainageways. The 2 to 6 inches of additional water stored in these "pans" accounted for a two to fourfold increase in grain sorghum and forage sorghum yield. (SWC 9-d1)

6. Impervious material between rows. Field studies in the Great Plains have demonstrated the importance of conserving moisture by using impervious material on the ridges between row crops. At Mandan, North Dakota, the yield increases attributed to covering the ridges with plastic have been 30 percent for sugar beets; 20 percent for alfalfa, tomatoes, and Russian wildrye; 40 percent for soybeans and field corn; and 60 percent for field beans and safflower. Sugar beet yields were higher on a sloping area that had plastic between the rows than on a conservation bench with an impervious contributing area of equal size. (SWC 9-d1)

At Big Spring, Texas, in a plant two, skip one row system, with sheet metal covers on the ridges between the rows, cotton lint yields were 520 pounds per acre as compared with 380 pounds for the treatments without the cover. Attempts to increase runoff from the ridge area by compacting the soil and not applying the impervious material were not successful. Various systems of partial covers on ridges in row crops can be used to a decided advantage in semiarid areas if a suitable low-cost material can be developed. (SWC 9-e1)

7. Snow trapping. At Akron, Colorado, wheat yields between sorghum barrier rows were 21 bushels per acre as compared with 17 bushels on the area with no barriers. In these studies, two sorghum barrier rows were planted every 60 feet in the wheat field. The maximum snow deposit was 5 feet from the barrier rows. (SWC 10-d1)

B. Factors Affecting the Loss of Water by Evaporation

1. Water lost by evaporation. At Sidney, Montana, 4 inches of supplemental water applied to bare fallow in June was lost by evaporation by late September. During the 21-month fallow period, only 23 percent of the precipitation was stored in the soil. About three-fourths of this moisture was stored during the first overwinter period. (SWC 9-d1)

2. Size of container. At Fort Collins, Colorado, laboratory studies indicate that the diameter of the container used in experiments greatly affects the loss of water by evaporation. This is especially true during the first stage of drying when evaporation is constant and largely controlled by climatic factors. During the second stage when the surface soil is dry, neither can diameter nor climatic factors appear limiting, but soil properties determine the evaporation rate. These results emphasize that comparisons of any influence treatments might have on evaporation in the laboratory must be made on the same diameter containers. (SWC 9-d1)

3. Mulches. At Weslaco, Texas, evaporation was reduced with equal effectiveness by a 0.6-inch layer of mortar sand and a 2-inch layer of cotton burs. The average soil suction at 12 inches was 136 and 137 centimeters of water under the cotton bur and sand mulch, respectively. Under bare fallow and a newly established Bermudagrass sod, the suction was 213 and 270 centimeters, respectively. Techniques for effectively using plant residues in farming systems have not yet been worked out. (SWC 9-e1)

On the Jornada Experimental Range in New Mexico, spraying cationic asphalt emulsion and petroleum resin films or applying a straw mulch did not conserve sufficient moisture to establish a stand of black grama grass. In the laboratory, the infiltration rate was unchanged with resin, but was reduced significantly with asphalt. Evaporation losses were rapid from untreated soils, intermediate from resin-treated and slow for asphalt-treated soils. Although the drying rate varied with treatment, there was little difference in final moisture content. (SWC 9-e1)

4. Surface drying. A technique for measuring the soil depth at which evaporation occurs was developed at Fort Collins, Colorado. The method requires the measurement of heat flow with depth. Immediately after wetting, evaporation from a Loveland sandy loam was mainly at the soil surface. After 23 days, the soil surface was dry and the zone of evaporation was at the 3-centimeter depth. (SWC 9-d1)

5. Unsaturated drainage. The relative contribution of evaporation and unsaturated drainage to total moisture loss from a 6-foot soil profile was evaluated during 1963 at Riverside, California. The accretion of moisture in dry soil below the 6-foot profile was concluded to be unsaturated drainage. Unsaturated drainage of 0.6 inch was measured over a 5-week summer period in a Hanford very fine sandy loam 6-foot profile which had been previously wetted. The moisture loss by evaporation over the same period was 2.14 inches. These results show that there can be some loss of water due to deep percolation in profiles with moisture contents below field capacity. (SWC 9-g1)

C. Factors Influencing the Use of Moisture by Crops

1. Water table. Soil moisture and water table measurements made during the 1963 crop season at Weslaco, Texas, indicate that a substantial portion of the moisture used by grain sorghum comes from the water table. Water table depths of 3.4, 5.2, and 7.6 feet at planting time were associated with grain yields of 3,630, 2,670, and 1,550 pounds per acre. During the growing season, the water table declined from 60 inches at seeding to 72 inches at maturity. These findings agree with similar studies with cotton at this location. (SWC 9-e1)

2. Stored moisture. Soil moisture storage and depletion studies conducted on Pullman silty clay soils at Bushland, Texas, again show the importance of moisture movement in the vapor phase. A mathematical consideration of average yields and seeding-time soil moisture values from seven separate systems, shows the soil moisture at seeding in the 3 to 6 foot zone strongly influences wheat yields even though soil moisture sampling at seeding and harvest did not indicate any apparent removal of moisture. This suggests that there might have been water movement into this zone in the winter and out of the zone in the summer. This movement could have occurred as a result of the change in temperature gradient. These results tend to explain why so much confusing moisture data have been collected in dryland experiments over the years. (SWC 9-e1)

3. New equipment. At Fort Collins, Colorado, an inexpensive portable integrator was developed. The instrument will allow integration of net radiation, solar radiation, and heat flow in field experiments. The development of this instrument makes evaluation of these important evapotranspiration variables more manageable. (SWC 9-d1)

4. Crop response to water. At Akron, Colorado, the value of a small amount of stored soil water as reflected by the yields of several crops has been studied. Sudangrass yields were 1,860 and 4,850 pounds per acre when the seasonal evapotranspiration rates were 11.5 and 14.6 inches, respectively. Millet yields increased from 580 to 3,000 pounds per acre with an increase in water use from 8 to 11 inches. Grain sorghum and forage sorghum yields increased from twofold to fourfold, while the evapotranspiration rate increased only one or twofold. These data emphasize the differences in water-use efficiency of different crop species. (SWC 9-d1)

5. Plant population. Studies in western Minnesota and eastern South Dakota have shown that water-use efficiency increases as plant population, grain yields, and dry matter yields increased. Increasing corn population from 6 to 18 thousand plants per acre increased soil moisture use only slightly, but significantly increased corn yields. Optimum population varied from 15 to 21 thousand plants per acre. When the corn yield was 60 bushels per acre, 1 inch of moisture produced approximately 3.3 bushels, whereas 1 inch of water produced 7.0 bushels of corn when the yield was 120 bushels. (SWC 10-c1)

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AREA 10: SOIL PROPERTIES, PROCESSES, AND MANAGEMENT IN RELATION TO THE CONSERVATION AND EFFICIENT USE OF LAND AND WATER RESOURCES

Problem. The soil is the source of the nutrients required for plant development. When chemicals are applied to the soil, they usually react with the soil before the plant uptake process begins. The nutrient ion finally is found in the top of the plant where it performs its metabolic function. To reach this end point, the ion passes through various chemical reactions, most of which are not understood.

Soil tilth and structure control many of the responses of the plant to soil management. All too often, visual improvement of the physical properties of the soil has been observed in the field, yet these physical attributes cannot be quantitatively described because of a lack of methods and procedures. The research progress on soil tilth is hampered by a lack of understanding of the forces involved in holding soil particles together in stable crumb structure. If an understanding of the factors was improved, our scientists could develop practical methods for exerting a real influence over the structure of our soils.

Fertilizer use in this country is presently well over 3 million tons per year. With low-cost commercial fertilizer now available, our farming has become much more efficient and economical. Fertilizer practices still remain largely empirical, however, and nutrient imbalance is common.

Large amounts of pesticides and growth regulators are used. These compounds are either applied to the soil or ultimately reach the soil. The fate of these compounds in the soil must be known in order that the residual amounts may be predicted. Soil organic matter is constantly undergoing changes as a result of the activities of micro-organisms. The role of the soil flora and fauna in the mineralization of organic materials and chemicals added to the soil is not understood.

USDA AND COOPERATIVE PROGRAM

The Division program involves microbiologists, chemists, physicists, and plant physiologists working on basic and applied problems associated with developing principles for soil and water conservation. Nutrient requirements --uptake and balance, are being conducted at Beltsville, Maryland; Marcellus, New York; University Park, Pennsylvania; Blacksburg, Virginia; Rio Piedras, Puerto Rico; State College, Mississippi; Watkinsville, Georgia; Thorsby, Alabama; Florence, South Carolina; Morris, Minnesota; Mandan, North Dakota; Newell, South Dakota; Fort Collins, Colorado; Sidney, Huntley, and Bozeman,

Montana; Weslaco and Bushland, Texas; Woodward, Oklahoma; Riverside and Brawley, California; Tucson, Arizona; Logan, Utah; Corvallis and Pendleton, Oregon; and Prosser, Washington.

Research concerned with soil chemical properties is being conducted at Beltsville, Maryland; Auburn, Alabama; State College, Mississippi; Rio Piedras, Puerto Rico; Watkinsville, Georgia; Fort Collins, Colorado; Mandan, North Dakota; Weslaco, Texas; Brawley, California; Logan, Utah; Prosser, Washington; and Corvallis, Oregon.

Tillage, residue management, and cropping systems' research is being conducted at Blacksburg, Virginia; Orono, Maine; Marcellus, New York; New Brunswick, New Jersey; Holly Springs, Mississippi; Thorsby and Auburn, Alabama; Fleming and Watkinsville, Georgia; Rio Piedras, Puerto Rico; Florence, South Carolina; St. Paul and Morris, Minnesota; Ames, Iowa; Madison, South Dakota; Akron, Colorado; Bozeman, Sidney, and Huntley, Montana; Mandan, North Dakota; Mitchell and Lincoln, Nebraska; Bushland and Big Spring, Texas; Woodward, Oklahoma; Brawley and Riverside, California; Pendleton and Ontario, Oregon; Prosser and Pullman, Washington; and St. Anthony, Idaho.

Soil microbiology research is being conducted at Beltsville, Maryland; Minneapolis, Minnesota; Lincoln, Nebraska; Fort Collins, Colorado; and Prosser, Washington.

The Federal scientific effort devoted to research in these areas totals 105.0 professional man-years. Of this number, 38.0 are devoted to nutrient requirements--uptake and balance; 23.0 to soil chemical properties; 35.0 to tillage, residue management and cropping systems; and 9.0 to soil microbiology. At all locations, the work is in cooperation with the experiment stations in the respective states.

PROGRAM OF STATE EXPERIMENT STATIONS

A very substantial research effort is in progress at the State experiment stations on fundamental and applied aspects of soil properties, processes and management. The studies cover cation and anion fixation on clay mineral surfaces, exchange processes and rates between solid and liquid phases, activation energy for ion movement, the mechanisms of fixation of potassium, ammonium and other ions, and a variety of related processes. Other studies concern the rate and mechanism of nutrient uptake by plant roots as influenced by nature of the nutrient, ion balance, oxygen and carbon dioxide tension, temperature and other factors. Other studies concern effects of nutrient ratios and type of clay mineral on nutrient release and uptake.

Investigations on soil physical properties seek better understanding of the mechanism and forces binding soil particles into aggregates, the role of clay in aggregate formation, the nature of interaction between organic matter and silicate minerals, and the influence of pressure and load conditions on particle behavior. Soil microbial investigations concern nitrogen fixation and transformation, factors influencing legume inoculation, organic matter accumulation and decomposition, and environmental factors influencing microbial processes.

Research is under way on nutrient relationships of soils and methods of determining nutrient availability. Other studies concern the type, time, rate and manner of fertilizer application for different crops under varied soil and climatic conditions. Studies are in progress on trace element chemistry and nutrition of specific crops. Lime reactions and relationship to nutrient availability are being investigated. Interactions of fertilizer needs and applications with other soil and crop management practices are under study.

Several State stations have work in progress on the behavior and fate of radiation isotopes that reach the soil from fallout and other sources.

Cooperative research between several states is in progress under the following regional projects: NE-11 on soil aeration and root development; NC-55 on soil organic matter; NC-56 on soil structure; W-66 on the nature and control of soil crusts; S-53 on soil testing; and S-51, NE-39, and W-31 on the loss, retention and transformations of soil nitrogen.

The total research effort of the State experiment stations on soil properties, processes and management is 292.9 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Nutrient Requirements--Uptake and Balance

1. Recovery of applied nitrogen. Several field studies have been conducted to determine the availability of nitrogen from materials with water resistant coatings. At Weslaco, Texas, resin-coated ammonium nitrate did not increase cabbage yields more than the noncoated material. The nitrogen content of the cabbage decreased as the thickness of the fertilizer coating increased. Soil samples analyzed for nitrogen following the crop indicated higher residual nitrogen on those treatments receiving coated fertilizer. (SWC 10-e2)

Results from studies at Riverside, California, show that soil temperature is a major factor in determining availability of soluble nutrients from resin-coated fertilizers. After two weeks' incubation in sand at temperatures of 5, 15, 25, and 35° C., urea coated with 13.2 percent resin had released 30, 39, 62, and 80 percent of its nitrogen, respectively. In terms

of percent nitrogen released in both sand and soil, an increase of 10° C. was equivalent to a doubling of the release rate. After 16 weeks, the coatings remained stable. This information suggests that the nitrogen release from resin-coated materials is retarded. (SWC 10-g2)

A detailed study was made at Beltsville of the recovery of fertilizer nitrogen from soil using N^{15}-tagged NH_4SO_4 and N^{15}-$NaNO_3$. With the nitrate source, analyses immediately after adding the fertilizer failed to recover about 5 percent of the fertilizer. When the fertilizer and soil were incubated 8 weeks, recoveries were slightly less. The soil pH and temperature of drying had little affect. With the ammonia source, the zero time recovery was almost 100 percent in samples of low pH soil dried at low temperatures, but the loss increased as the pH was raised and drying temperature increased. After 8 weeks' incubation, recoveries from both sources were approximately the same. (SWC 10-aB2)

Data are being collected at Mandan, North Dakota, on the fate of nitrogen from various sources applied to bromegrass and to cropping systems. Plant and soil analyses show that under irrigation about 40 percent of the nitrogen applied over a 2-year period was absorbed by plant tops, 30 percent was absorbed by roots, 5 to 10 percent remained in the soil as NO_3-N, and 20 to 25 percent was not accounted for. On dryland, about 25 percent was accounted for in tops, 10 to 25 percent in roots, 30 to 60 percent remained in the soil, and 0 to 20 percent was not accounted for. Applying N in small weekly doses to fallow plots resulted in 100 percent recovery of the N applied, and this treatment apparently had a priming effect upon the mineralization of soil N. In grassland soil, NH_4-N was always present in small quantities. The NH_4-N concentrations changed little with time or treatment, while NO_3 contents changed drastically. Fertilizer N was quickly immobilized in grassland, whereas the soluble N concentrations reached high levels on adjacent fallow soils receiving the same fertilizer treatment. Little mineralization of soil N occurred in grassland soils sprayed with a light application of Dalapon. This treatment killed the tops, but the roots remained alive. This information, though based on only one study, is immediately useful in making recommendations for fertilizing grasslands. (SWC 10-d2)

In a nitrogen fertilization study on crested wheatgrass at Newell, South Dakota, fertilizer N in the form of NO_3-N applied at the start of the study gradually moved to lower depths after 5 years. After the second season, no significant amounts of NO_3-N were found to a depth of 4 feet on irrigated plots, whereas plots that received no supplemental water still showed significant amounts at the 24- to 48-inch soil depths after the fourth season. Considerable amounts of fertilizer N remained unaccounted for. (SWC 10-d2)

The loss of gaseous nitrogen from a calcareous soil during nitrification was investigated at Brawley, California. When soil treated with either ammonium sulfate, sodium nitrite, or ammonium sulfate plus organic matter was incubated, essentially all the ammonium and nitrite nitrogen disappeared

at the end of 28 days. Gaseous nitrogen losses were less than 5 percent even when large amounts of nitrite accumulated in the soil. These small losses may be due to the stability of nitrite at the relatively high soil pH or due to the reaction of nitrite with organic compounds in the soil. The forms of the gaseous nitrogen produced were N_2O and N_2. These results suggest that the large losses of nitrogen found under irrigated conditions in the lower desert areas of California are not due to nitrite accumulation and decomposition. (SWC 10-g1)

2. Leaching of nitrogen. At Beltsville, the first phase of the study dealing with the movement of water and nitrate ions around sodium nitrate bands has been completed. A "dropout" phenomenon has been described which takes place in soils that have a moisture content greater than field capacity. Soil water moves under an osmotic force to the sodium nitrate band and as a result, a solution accumulates in this vicinity. Once the accumulating solution exceeds that which can be held by the capillary forces of the soil, the solution drops out of the band under the force of gravity. When a "U"-shaped shield is placed under the band, the "dropout" phenomenon is effectively controlled. (SWC 10-aB7)

Field studies to evaluate the effectiveness of "U"-shaped shields under fertilizer bands to reduce leaching were conducted on a Coastal Plains soil at Florence, South Carolina, and on a Piedmont soil at Watkinsville, Georgia. At both locations, the shield did not prevent N leaching. The field techniques will be altered before repeating the experiment next year. (SWC 10-b3)

3. Mineralization of nitrogen. At Fort Collins, Colorado, studies on the effects of time and temperature on indigenous fixed and exchangeable forms of NH_4^+-N in soils showed that temperatures of 250 to 300° C. for a period of 5 to 30 minutes increased the exchangeable NH_4^+-N of topsoils from three to six-fold. This increase in exchangeable NH_4^+-N is derived from organic matter decomposition. Both exchangeable and fixed forms of NH_4^+-N were lost from soils at temperatures of 400° C. or higher for a period of 5 minutes or longer. Fixed NH_4^+-N exhibits greater stability at temperatures of 400° C. or higher than exchangeable NH_4^+-N. However, the lengths of time the samples were heated and the temperatures studied did not provide a time-temperature relationship with sharp distinctions between these two forms of NH_4^+-N. (SWC 10-d2)

Pretreatment of soils with some organic compounds reduces the amount of NH_4^+ fixed from NH_4Cl. Glycine, L-proline, and ethylamine had the most pronounced effects. Sucrose, glucose, and gelatin had some effect, but citric acid and acetic acid had no influence. Sucrose, glucose, and gelatin probably become adsorbed on the clay and physically block entry of NH_4^+ to some of the fixation sites, thus reducing total fixation. Since glycine, L-proline, and ethylamine cause a much greater reduction in NH_4^+ fixation, some mechanism other than adsorption and blocking must be present. The fact

that all three of these compounds contained NH_2 groups, suggests that these compounds were being fixed. Data have been obtained showing that substantial amounts of ethylamine and glycine were fixed by vermiculite. This information adds a great deal to our knowledge of the mineralization of nitrogen. (SWC 10-d2)

At Corvallis, Oregon, basic studies concerning reactions of ammonia with soils have indicated possible important mechanisms whereby ammonia becomes fixed by soil organic matter. Using p-quinone as a model humic acid precursor, polarographic analysis of p-quinone-aqueous ammonia systems reveal the presence of two reducible intermediates active in the fixation of ammonia. The intermediates are probably mono- and di-substituted amino-quinones, which polymerize to form a highly conjugated heterocyclic compound containing nitrogen. The composition of the product varies with pH and ammonia concentration. A typical product prepared at pH 9.0 contained 8.78 percent nitrogen. These findings are useful in predicting what chemical reactions take place when anhydrous ammonia is applied to the soil. (SWC 10-f3)

At Beltsville, the effect of associated cations, including N^{15}-tagged ammonium, on the release of fixed ammonium to plants was studied. Two ammonium-fixing subsoils were treated with an excess of ammonium. The soils were then leached with KCl, $CaCl_2$, or NH_4Cl and cropped to sudangrass. Total uptake of fixed ammonium over an 8-week cropping period was relatively high, ranging from an average of 62 percent for the ammonium-treated sample to 85 percent for the calcium-treated samples. (SWC 10-aB1)

Previous findings at Beltsville that decreasing the cation exchange capacity of soils decreases the rate of nitrification during decomposition of alfalfa were confirmed in studies with other soils. The explanation offered for this phenomenon is that the nitrifying organisms Nitrobacter are inhibited by toxic accumulations of un-ionized NH_3. Ammonia produced by decomposition of alfalfa exists in an equilibrium of NH_3 and NH_4. Ammonium displaces the hydrogen ion from the exchange complex, thereby lowering the ammonia concentrations and the pH of the solution. The lower pH tends to reduce the NH_3 concentrations. If the soil has a low cation exchange capacity, there is not an abundance of hydrogen ions. This results in a high pH and levels of NH_3 high enough to be toxic to the nitrifying organisms. (SWC 10-aB2)

At Fort Collins, Colorado, organic colloids have been separated from mineral soil by a simple extraction with an acetone-H_2O-HCl solvent. These colloids are acids and show infrared adsorption in regions characteristic of OH or phenolic OH and carbonyl groupings. The solvent-colloid solutions from all soils tested emitted fluorescence energy with a maximum at 500 millimicrons and were activated by light energy of 465 millimicrons. This excitation and fluorescence corresponds closely to the values for many known metal complexes. The colloids have C/N ratios of about 30 to 1 and are

fairly stable to acid hydrolysis. Part of the N released by acid hydrolysis is in the form of amino acids. This information increases our knowledge of the nature and chemistry of organic matter. (SWC 10-d2)

In a laboratory study in Poland to determine the nature of the reactions between minerals and the organic fractions of the soil, the rate of organic matter decomposition was greatest in a sandy soil. When loam was added to the sand, the rate of decomposition decreased but the humus content increased. Field studies carried out on heavy and light soils confirmed the laboratory results. (E21-SWC-2)

4. Nutrient requirements of various crops. At Bozeman, Montana, inadequate N for the first week of plant development in solution culture resulted in greater P uptake by spring wheat than occurred when adequate N was supplied continuously. This indicates that low N levels may trigger some mechanism during the first week that results in abnormally high P absorption. Yield data indicate that some determinate factor for yield potential may also be altered within the first week by nitrogen deficiency. (SWC 10-d3)

At Beltsville, study of the significance of nutrient balance in relation to fertilizer usage has continued. Studies on the effect of various combinations of salts on the ionic content and growth of 18 species of plants have been conducted. The uptake rates of ions differ between plant species, and consequently, the various combinations of salts do not place the same stress on the organic acid concentration of each plant species. Within a plant species, the lowest yield was associated with high anion content. All species studied accumulated large amounts of chloride. Cotton accumulated large amounts of chlorides and sulfates. The chloride treatment resulted in an increased anion content and lower yields. These data suggest that the anion in fertilizers may be as important in crop production as some of the cations. (SWC 10-aB8)

Experimental plantings of sugarcane near Brawley, California, have shown the crop to be well adapted to that area of California. Good growth and high sugar yields have been obtained from several varieties using approximately 250 pounds of nitrogen per acre with frequent irrigations during the growing season. (SWC 10-g1)

In a 3-year study in the lower Rio Grande Valley of Texas, dryland grain sorghum on a Raymondville clay loam soil did not respond to nitrogen and phosphorus fertilizers. Yields averaged 3,000 pounds per acre per year. At Woodward, Oklahoma, on coarse-textured soils, wheat and grain sorghum yields are often limited as much by a deficiency of N as by a deficiency of moisture. Phosphorus deficiency is generally incipient. (SWC 10-e2)

At Weslaco, Texas, leaf nitrogen and phosphorus levels were related to the yields of sweet peppers. Values obtained from leaf tissue analysis for nitrogen accounted for 69 to 81 percent of yield variability. Values for

phosphorus were not directly related to yields. High soil phosphorus levels may account for the lack of correlation between tissue tests and yields. (SWC 10-e2)

At Watkinsville, Georgia, the influence of potassium sources, rates, and frequency of application on Coastal Bermudagrass forage production was studied on a Cecil sandy loam soil. Forage yields were similar for chloride, sulfate, and K-Ca pyrophosphate sources. Forage yields were 4.5 and 7.5 tons per acre for the 0- and 664-pound potassium rates, respectively. (SWC 10-b3)

In Puerto Rico on plots receiving high rates of lime, yields of tobacco were the same for six nitrogen sources. Similar results were obtained with corn. With coffee, sodium nitrate depressed yields, but five other nitrogen sources gave equal yield increases. Coffee responded to nitrogen and potassium and under intensive management yielded over 3,000 pounds per acre. The average yield for the Island is 150 pounds per acre. (SWC 10-b3)

At University Park, Pennsylvania, ladino clover grown in nutrient solution cultures high in phosphorus accumulated excess phosphorus which was utilized for growth by the clover after the nutrient solution was replaced with one containing no phosphorus. The greater the reserve of phosphorus in the plant, the longer growth continued after phosphorus withdrawal from the culture solution. Regardless of the size of the plant, the effect of withdrawing phosphorus from the nutrient solution showed up first in top growth. (SWC 10-a2)

Studies have been initiated at Beltsville to determine the effect of temperature and moisture on the release of soil potassium. Dry heat consistently increased the release of potassium, whereas moist heat (autoclave) depressed the release. (SWC 10-aB10)

In basic studies of the role of the plant in P uptake at Fort Collins, Colorado, methods have been developed for the separation and determination of the early products of phosphorus uptake in corn roots. Ribonucleic acid (RNA) concentration in corn roots is significantly increased by increasing the nitrogen supply to the plant. The rapid incorporation of significant amounts of newly absorbed phosphorus into RNA and the effects of nitrogen pretreatments show that RNA synthesis is sensitive to nitrogen and phosphorus supplies. The pool of inorganic phosphorus in corn roots does not appear to have a regulatory effect on phosphorus uptake rates from external solution. (SWC 10-d1)

Studies on southern California rangeland indicated a significant residual effect of nitrogen and phosphorus fertilizers. A dry matter yield increase of 3,300 pounds per acre was obtained over a 2-year period where 60 pounds of nitrogen and 26 pounds of phosphorus were applied to annual rangeland. Two-thirds of this increase was measured the second year as residual effect, even though rainfall was approximately one-half that of the previous season. (SWC 10-g2)

The application of phosphorus alone to range resulted in domination by the legume, bicolor lupin (Lupinus bicolor), and the weed, alfilaria (Erodium cicularium). The increased legume growth during the year of phosphorus application was reflected in increased growth of grass species during the following year due to the nitrogen contributed by the legume. Results from four years of field work indicate that the coastal range area of the State of California is deficient in nitrogen and phosphorus. (SWC 10-g2)

5. Influence of soil texture and moisture on phosphorus diffusion. At Fort Collins, Colorado, basic research was continued on the measurement of the diffusion coefficient (Dp) for P in soils, the ratio of labile P to soil solution P (capacity factor), and soil texture and soil moisture content and their significance to P uptake by plants. The diffusion coefficients for P were measured by two independent methods. In a steady-state method, Dp was measured directly without a need to measure separately the capacity factor. The transient-state method requires an independent estimate of a phosphate capacity factor, which varies between 100 and 200 for the soils used. If these values were not used in the calculation, an apparent diffusion coefficient would be measured, which would be much smaller than the true value. The agreement of Dp by these two methods constitutes proof that a capacity factor must be taken into consideration when diffusion coefficients for P are measured in soil by transient-state methods. The effect of soil texture variations on plant uptake of P can be explained by the differences in the diffusion coefficients and the capacity factor. Clay soils have larger values of Dp and the capacity factor than sandy soils; therefore, at equal concentrations of P in solution, the plant absorbs P faster from the clay soil. Root hairs for corn appear to be about six times more efficient than the main roots in absorbing P from soil per unit of root surface area. These data will be most helpful in predicting the phosphorus requirements of various crops. (SWC 10-d1)

6. Influence of soil temperature on phosphorus nutrition. Studies were continued at Mandan, North Dakota, on the interacting effects of soil temperature and soil fertility levels on spring growth of cereals in the Northern Plains. In two growth-chamber studies, both soil temperature and P level interacted in affecting growth and P uptake. At soil temperatures of 59° F., or lower, $NaHCO_3$-soluble P concentrations of 12 to 15 ppm. were sufficient for maximum growth. However, as the soil temperature was increased above 59° F., the results suggest that progressively higher $NaHCO_3$-soluble P levels are required for maximum plant growth. Factors limiting growth at below optimum soil temperatures are different from those active at above optimum soil temperatures. Total P absorption by barley continued to increase up to maturity for all combinations of P fertilization and soil temperature. Temperature had only a small effect upon total P absorbed by tops, when plants were harvested at the same stage of growth. This information is of great value in predicting soil and fertilizer phosphorus availability in soils that are inherently cold in the spring. (SWC 10-d1)

7. Micronutrients. At Fort Collins, Colorado, studies were continued on the interrelationships of phosphate, zinc, and iron in plant nutrition in both soils and solution cultures. Corn and pinto beans responded differently to various nutrient solution levels of iron, phosphorus, and zinc. In corn, a high level of phosphorus-induced iron and zinc deficiency symptoms and reduced yield. The addition of zinc to corn had an antagonistic effect on iron nutrition and depressed the yield. The antagonistic effect of zinc on iron was associated with a low uptake of iron by the corn plants. With beans, the addition of phosphorus did not cause zinc or iron deficiencies to occur. (SWC 10-d3)

At Fort Collins, Colorado, work has started on the importance of sulfur to maintenance of organic matter and nitrogen levels in Great Plains soils. Sulfur must be added along with adequate N and P to obtain a maximum rate of decomposition of cellulose (also other C additives) in many soils. A ratio of carbon to sulfur of 100 to 1 in the added materials appears necessary to insure a maximum rate of decomposition of cellulose, especially if the C addition is more than 0.4 percent. Below this level, a 300 to 1 ratio may be sufficient. For glucose, a 900 to 1 ratio is sufficient. Fertilizer nutrients (N, P, S) appear to influence only the rate of decomposition. When adequate N, P, and S are added with cellulose, a higher rate of cellulose addition will result in a faster percentage decomposition during the first 20 to 30 days of incubation under laboratory conditions. Beyond this point, the rate of decomposition is inversely related to the quantity of C added. (SWC 10-d3)

Studies conducted near Pendleton, Oregon, indicate that single application of sulfur applied as gypsum will supply the sulfur needs of dryland winter wheat grown in a wheat-pea rotation for several years. On field plots fertilized with sulfur in 1959, beneficial effects have been noted in each of three wheat crops. On plots that received 15 or more pounds of sulfur per acre in 1959, the 1963 crop yielded 13 bushels per acre more wheat than where no sulfur had been applied. These results clearly indicate that under the dryland conditions of eastern Oregon, a single application of 15 pounds of sulfur per acre will supply the sulfur needs of at least three winter wheat crops. (SWC 10-f2)

Studies are continuing on the factors responsible for zinc deficiency in field crops. Zinc sulfate and a chelated zinc material were compared, using Red Mexican beans grown on a zinc-deficient soil in the Columbia Basin. Both sources were equally effective when applied at the rate of 10 pounds of zinc per acre. At lower rates of zinc, bean yields were higher on the zinc sulfate plots than on those receiving the chelated source. (SWC 10-f2)

At Prosser, Washington, and Beltsville, Maryland, experiments conducted in growth chambers indicate that two varieties of beans (Sanilac and Great Northern 1140) and two varieties of potatoes (White Rose and Russet Burbank) are susceptible to zinc deficiency induced by high levels of phosphorus.

Chemical analysis indicate that the disorder was not brought about by low zinc concentration in the plant, since normal appearing and affected plants of the same size contained similar amounts of zinc. (SWC 10-f2)

In a field experiment conducted near Prosser, Washington, corn following 3 years of sugar beets showed severe zinc deficiency symptoms where no zinc fertilizer had been applied. Corn following 3 years of sorghum with or without zinc fertilizer made good growth, as did that following sugar beets where zinc had been applied. Analysis of the sugar beet and sorghum crops indicated no differential zinc removal by the two crops during the 3-year precropping period. Additional work is underway to elucidate the nature of the effect. (SWC 10-f2)

During the year, some progress was made at Lucknow, India, in a study to determine the influence of iron on the nutrition of two crops. The results showed that iron deficiency resulted in marked accumulation of nonprotein nitrogen in maize and radish. In both crops, the reducing sugars were markedly depressed by iron deficiency. These findings give some understanding of the factors associated with iron deficiency. (A7-SWC-17)

The distribution of micronutrients in soil minerals is being studied at Pulawy, Poland. Results show that pyroxenes and iron oxides are concentrated in the silt and sand fractions. Two soils, developed on basalt had the highest micronutrient (copper, iron, manganese, zinc, nickel, cobalt, and molybdenum) concentrations in the surface horizons. These data make available for the first time mineralogical data and the distribution of minerals as a function of both particle size and depth for a variety of micronutrients on the same soil. (E21-SWC-7)

8. Nutrient requirements of subsoils. Effects of topsoil removal on soil productivity are being studied at Bushland and Weslaco, Texas. At both locations when no fertilizer was applied, dry matter (grain or forage sorghum) yields and nitrogen uptake were reduced proportionally to the amount of surface soil removed in the leveling operation. At Weslaco, four methods of making 12-inch cuts were compared. In three of these, a portion of the topsoil remained after leveling. In the fourth, an ordinary 12-inch cut was made. Nitrogen and phosphorus fertilizer compensated for the soil removal where part of the topsoil remained, but not where all topsoil was removed. Apparently, topsoil contained other essential elements not supplied by the subsoil. At Bushland, where successive depth increments of soil were removed, applied nitrogen and phosphorus compensated for 12 inches of soil removal. Greenhouse studies on seven soils indicate that the aeolian and alluvial soils of the Southern Great Plains may be leveled without permanent impairment of productivity. (SWC 10-e2)

B. Soil Chemical Properties

1. Soil acidity and plant growth. At Beltsville, wheat varieties have been tested to determine their tolerance to acid soils that were high in soluble aluminum. Atlas 66 wheat proved to be more tolerant than the Monon variety. Root yields reflected this difference to the greatest degree. Nutrient solution studies showed a higher concentration of aluminum in the roots of Monon than in the tolerant Atlas. In nutrient solution and soils, it was shown that Atlas raised the pH more than did Monon. These findings led to the conclusion that the differential aluminum tolerance between the two wheat varieties resulted from differential pH changes in the soil immediately surrounding the roots. Preliminary studies with a large number of barley varieties have shown that there is a wide range of tolerance to the high-aluminum Bladen soil. This finding is proving to be a valuable plant breeding tool in developing varieties adapted to acid soils. (SWC 10-aB8)

In Puerto Rico, yields of tobacco following grass were increased tenfold by lime applied over a 4-year period to the grass. These results emphasize the importance of applying adequate lime to grass when high rates of nitrogen fertilizer are used. Coffee responded to lime on some soils, but not on others, even when the pH was as low as 4.0. The response to lime was associated with the soluble manganese in the soil. Coffee is susceptible to manganese toxicity. (SWC 10-b1)

At Beltsville, Maryland, studies were conducted to determine the percentage of limestone particles that became coated with colloidal material. Limestone particles (12-14 mesh) were incubated in selected soils for 12 months. Samples were taken monthly and the particles were recovered and examined. Total surface area of the particles increased rapidly during the first month of incubation, but then only slowly through the next five months, after which, there was no change. Large differences occurred in the solubility rates, and were associated with the soils used for incubation. The differences in solubility rates were correlated inversely with the concentration of phosphorus on the surface of the particles and directly with the concentration of iron or aluminum on the particle surface. These findings explain the lack of response of some acid soils to liberal applications of limestone. (SWC 10-aB7)

On the Freeman soil near Rockford, Washington, alfalfa yields on plots plowed 6-inches deep were increased from 0.9 ton per acre to 1.3 tons when lime, phosphorus, and sulfur were applied. On plots plowed to a depth of 4 feet, yields were increased from 1.7 tons per acre to 2.8 tons per acre when lime, phosphorus, and sulfur were applied. (SWC 10-f1)

At Auburn, Alabama, a large difference was found among regional soils in the behavior of seedling roots at equivalent subsoil pH levels. In model acid profiles, surface-applied Ca salts moved downward at a rate dependent upon the complementary anion. The degree of sorption of the Ca by the acid

subsoil also was largely a function of the anion involved. This reaction was most pronounced at low pH levels. In field experiments, the depth of rooting was improved considerably by raising subsoil pH from 5.1 to 6.1. In culture solutions, primary cotton root growth was influenced by the oxygen level in the absence of aluminum or at the intermediate aluminum level (0.4 ppm.). At the high aluminum level (0.8 ppm.), however, oxygen did not influence root growth. (SWC 10-b6)

2. Soil pesticide complexes. At Beltsville, Maryland, the adsorption-desorption behavior of a number of pesticides on clays has been studied. Results showed that there was considerable adsorption on montmorillonite, but only an insignificant amount on kaolinite, vermiculite, or illite. The degree of adsorption on montmorillonite was related to the types of chemical groups in the 2, 4 and 6 positions on the triazine ring. X-ray diffraction data indicate that the triazines are adsorbed in the interlayer spaces of the montmorillonite. (SWC 10-aB4)

Studies with a triazine herbicide on a large group of soils showed a wide variation in the percentage of the material adsorbed on the solid phase. Acid soils were more adsorptive than alkaline soils. Alternate wetting and drying reduced retention of the pesticides. (SWC 10-aB4)

C. Tillage, Residue Management, and Cropping Systems

1. Soil structure. Studies at St. Paul, Minnesota, to determine what organic or inorganic constituents of soils contribute to stability have resulted in quantitative values for slaking and dispersion. The constituents have been divided into three general classes according to ease of removal by various oxidizing and extraction reagents. After removal and identification of the bonding agents, their role or importance in stabilizing natural soil particles can be ascertained. This information is needed in order that we may someday understand how a soil crumb is held together. (SWC 10-c3)

Microscopic examinations of thin sections of soil aggregates at Ames, Iowa, have shown that the layer around the edge of each aggregate is more dense than the interior. The thickness of the dense layer appeared to be constant and was independent of aggregate size. Thus, the volume proportion of the dense layer decreases as aggregate size increases, which accounts for the negative correlations between density and aggregate size obtained from the data. In many aggregates, a thin layer of amorphous material, possibly organic in nature, was found on the periphery. This concentration of organic material on the surface may account for differences in organic carbon as previously reported. (SWC 10-c2)

At Madison, Wisconsin, infiltration on Miami silt loam was decreased nearly 50 percent by a surface crust created by removing a corn stover mulch. Infiltration rates from minimum-tilled, stover-mulched corn were much higher than under a legume-grass meadow. Minimum tillage treatments increased the

total porosity of the plow layer by about one-third, but most of the increase was lost via surface settling during simulated rainfall. The infiltration rate on a stover-mulched soil in corn for 8 consecutive years was about equal to the rate of infiltration in a virgin soil under forest cover. These studies have demonstrated that infiltration rates can be maintained at high levels under intensive corn culture if a mulch is maintained on the soil surface to prevent formation of a surface seal and if the plow layer contains large pores or voids. (SWC 10-c2)

2. Tillage. At Morris, Minnesota, two important soil parameters, total plow layer porosity and random roughness, are being used to evaluate water management in the soil zone between crop rows. The results varied with soil type and the moisture content at the time of tillage. The total porosity of the tilled layer was usually, but not always, less on a plow, disk-harrow system of tillage for corn than on a minimum tillage system consisting of plowing and wheel-track planting. In the Kranzburg soil, disking and harrowing the interrow area following plowing increased porosity in all five experiments. In the Nicollet soil, the same treatment increased porosity in 4 out of 9 cases, and in the Barnes soil, in 3 out of 11 experiments. Within a soil type, the effects of tillage treatment on total porosity have been evaluated by the ratio of the percent water by weight at time of tillage to the moisture content at the lower plastic limit. When the ratio approaches 1.0, the point of plastic consistence, porosity increases result from disking and harrowing. When the ratio is less than 1.0, porosity decreases result from disking and harrowing. (SWC 10-c2)

Plowing (wheel-track) significantly increased random roughness, but a subsequent disking and harrowing operation (conventional) reduced the roughness to the level observed on untilled surfaces. Post-plant cultivation also significantly increased roughness on all preplant tillages. Generally, there were no differences in roughness due to differences in seedbed tillage treatments at the end of the growing season when there was no post-plant cultivation. Random roughness was not closely related to the moisture content of the soil at time of tillage. This information, though based on a relative short period of study, is useful in developing tillage guides for the Corn Belt. (SWC 10-c2)

On loess soil at Holly Springs, Mississippi, corn grain yields were 30 percent higher with wheel-track and lister planting than with either conventional or direct planting methods. Planting in residue with minimum preparation plus using herbicides to control weeds has produced yields equal to those obtained with the conventional method. (SWC 10-b5)

Yams, tobacco, corn, beans, bananas, sugarcane, and taniers were successfully grown on steep slopes with no tillage in Puerto Rico. At Florence, South Carolina, similar yields of corn planted in Coastal Bermudagrass sod were obtained with lister-plant, turnplow, and rip-plant tillages.

Results of a 3-year study at Watkinsville, Georgia, show that where soil moisture is not a limiting factor, corn can be grown in either Coastal Bermudagrass or fescue sod. (SWC 10-b5)

Corn yields in Virginia with 4 consecutive years without tillage averaged 80 bushels per acre as compared with 73 bushels for conventional tillage. Corn was grown with no disturbance of the sod except as needed to hand-plant the seed. Equipment for planting corn in undisturbed sod is being developed and tested at Blacksburg. (SWC 10-a1)

Results of experiments conducted on Freeman silt loam near Rockford, Washington, show that deep-plowed (36 inches) soil contained 1 inch more available moisture at the beginning of the growing season than did the normal plowed (6 inches) soil. Moreover, winter wheat utilized approximately 2 inches more moisture from the deep-plowed than from the normal plowed soil. Deep plowing disrupted the dense B_2 horizon, thus increasing the effective depth of the soil as a moisture reservoir and as a medium for root growth. On deep-plowed land, wheat yielded 7 bushels per acre more than on normal plowed land. Wheat yields were increased 20 bushels per acre by a combination of deep plowing and adequate fertilization. After 7 hours, the total water intake was 6.2 inches for the normal plowed soil, and 3.2 inches for the deep-plowed soil. (SWC 10-f1)

On the Chilcott (nonsaline-nonsodic) and Sebree (solodized-solonetz) soils near Caldwell, Idaho, crop yields in 1963 were increased as a result of deep plowing in 1959. In 1963, corn yields on the Chilcott soil were 67 bushels per acre on land plowed to the usual depth, and 109 bushels per acre on land plowed 30-inches deep. Comparable yields resulting from these treatments were measured for wheat in 1960 and alfalfa in 1961 and 1962. The effect of deep plowing was even greater on the sodium-affected Sebree soil. Corn yielded 15 bushels per acre on the conventionally plowed area and 117 bushels per acre where the land was plowed 30 inches deep. Yields on plots receiving 12 tons of gypsum and conventionally plowed were 77 bushels, whereas on the deep-plowed plots, the gypsum treatment yield was 108 bushels per acre. The beneficial effects of deep plowing stem from the reclamation processes accomplished by mixing surface and subsoils, thus allowing better penetration of water and consequent leaching of exchangeable sodium and soluble salts. The improved soil conditions and the long-lasting effects of the treatments indicate that effective reclamation of the Sebree soil has been achieved by these treatments. (SWC 10-f1)

3. Tillage pans. Intensive studies of the physical environmental factors influencing plant root growth have been made at Auburn, Alabama. Tillage pans high enough in density to seriously inhibit cotton taproot penetration were found to occur commonly in the subsurface zones of Coastal Plains' soils. Moisture affected soil strength as much as or more than density. (SWC 10-b6)

At Big Spring, Texas, rates of cotton growth and lint cotton yields were reduced as soil strength at field capacity increased to 25 or 30 bars. In an experiment where cotton was sprinkler irrigated the first 3 weeks after emergence and then dry-farmed until maturity, lint cotton yield was 470 pounds per acre where soil strength was 5 bars, 350 pounds per acre where soil strength was 20 bars, and 285 pounds per acre where soil strength was 30 bars. In a companion experiment at Big Spring, growth rates and dry matter yields of 4 species of grasses were significantly reduced as soil strength at field capacity increased to 25 bars. Increases in soil strength above 25 bars did not further reduce grass growth or yield. (SWC 10-e1)

At Woodward, Oklahoma, results continued to show that tillage deep enough to disrupt soil pans does not increase grain sorghum yields in years of normal or above normal rainfall. However, soil pans severely reduced sorghum growth during the drought period of 1952-56. (SWC 10-e1)

In laboratory studies at Bushland, Texas, investigations were conducted to determine effects of soil moisture tension, temperature, and planting depth on the relation between soil strength and seedling emergence. With 4 of 6 soils tested, small amounts of compression apparently increased seedling emergence, but emergence was progressively decreased by increases in soil strength greater than 3 bars. When strength of Miles soil exceeded 13 bars, no emergence occurred. With the other 5 soils tested, no emergence occurred when strength exceeded 18 bars. (SWC 10-e1)

At Temple, Texas, a rapid method has been developed for taking undisturbed soil cores, 16 to 38 inches in diameter and 4 to 9 feet long, in a Houston Black clay profile. This is accomplished by (1) placing a static load on top of a vertical steel cylinder of the desired length and diameter, (2) allowing the weight to slowly press the cylinder into the soil, (3) removing the weight, and (4) pulling the cylinder containing the soil core out of the ground. Usually less than 1 percent decrease in soil volume occurs. These soil cores, representing natural soil structural conditions, will be useful as lysimeters for transpiration and evaporation studies, and for saturated and unsaturated moisture flow and evaporation studies. (SWC 10-e1)

4. Mulches. At Akron, Colorado, the growth of winter wheat in the fall was inhibited by straw mulches even though the nitrogen level was high. These investigations indicate that some factor, such as soil temperature or toxic conditions, is primarily responsible for these differences in plant growth. (SWC 10-d5)

At Bozeman and Huntley, Montana, winter wheat straw samples were placed in a fiber glass screen and exposed 1 inch above the soil surface, placed on the soil surface, and buried 5 inches below the surface in May 1962. At the end of 18 months, weight loss resulting from decomposition of the buried residue samples averaged 92.7 percent at Bozeman and 98.0 percent at

Huntley. The decomposition of straw on the soil surface was 31 percent at Bozeman and 40 percent at Huntley. The decomposition rate of the straw exposed 1 inch above the soil surface was 22 percent at Bozeman and 34 percent at Huntley. (SWC 10-d5)

Translucent plastic with slits to permit entrance of water from rainfall greatly increased the efficiency of water use by corn in New York. Yields of corn averaged 145 bushels per acre under slit plastic as compared with 111 bushels for control plots without plastic. On plots where the plastic was sealed around the corn stalks, 127 bushels of corn per acre were produced with a little over 4 inches of water in the soil at planting time. (SWC 10-a1)

An asphalt mulch can markedly increase soil temperature. In preliminary results obtained at Prosser, Washington, the increase in soil temperatures resulted in increased germination and emergence of early-planted crops such as sugar beets and sweet corn. Clear plastic materials have negligible effect, and loose materials such as coal dust are not satisfactory because excessive amounts are required, and they are subject to movement by wind. (SWC 10-f1)

5. Cropping systems. Studies at Fleming, Georgia, indicate that snapbeans, cucumbers, and sweet potatoes can be grown successfully on Coastal Bermudagrass sod if good land preparation and cultivation practices are used. Hay production from the Coastal Bermudagrass the summer following the vegetable crop was average for the soil type and fertilizer practices used. (SWC 10-b4)

Forty bushels per acre of rye were produced during the winter and spring months on Coastal Bermudagrass sod at Watkinsville, Georgia, without decreasing the Bermudagrass yield during the following summer months. These results show that excellent year-round utilization of land and climate can be achieved by growing small grain for seed in combination with Coastal Bermudagrass for hay. (SWC 10-b4)

At Watkinsville, Georgia, corn production following alfalfa, Coastal Bermudagrass and fescue sod was significantly higher than continuous corn at nitrogen levels ranging from 0 to 160 pounds N per acre. Corn in the sod-based cropping systems made more efficient use of available soil moisture and applied N. (SWC 10-b4)

At Florence, South Carolina, results of corn-Coastal Bermudagrass rotation studies indicate that the grass had some beneficial effects on first-year corn yields after grass, but little effect on yields of second- and third-year corn. Crop residues and roots incorporated with soil contributed 150 pounds per acre of total N to the soil. Grass preceding corn tended to decrease nematode infestations. (SWC 10-b4)

Winter cover crops annually and sod crops at 3-year intervals in a vegetable-crop rotation in New Jersey improved soil tilth over a 9-year period as measured by soil tests. Organic matter content in the plowed layer increased in the sod rotations over the period. (SWC 10-a1)

Experiments in Virginia and New York to evaluate yields of corn planted directly in sod after spraying with herbicides, and on soil conventionally tilled, show that yields for corn planted directly in sod are a little higher than conventional tillage. (SWC 10-a1)

A comparison of various cropping practices in Imperial Valley, California, showed that a cropping system that included manure applications resulted in 10 percent more sugar beets than cropping systems without manure. Returning crop residues increased the sucrose percentages of sugar beets and the yield of sugar. (SWC 10-g1)

Wide row spacing of sorghum in a fallow system has given highest yields at Akron, Colorado. Yields for the past 3 years in 56-inch-wide rows averaged 31 bushels per acre compared with 28 bushels per acre for 42-inch-wide row spacing. Under continuous cropping, yields were very low and row spacing had little influence. (SWC 10-d4)

Soil temperature appears to have more influence on barley growth when expressed in terms of equal plant age than equal phenological development. Laboratory studies at Mandan, North Dakota, show that plants with 72° F. soil temperature initially grew fastest, but were surpassed in growth rate by the 60° F. plants after about 3 weeks. Growth slowed down markedly at both 60° and 72° F. after the soft dough stage. At 48° F., however, growth was very slow the first 3 weeks, then proceeded at a steady rate until maturity. Soil temperature had only a slight effect on dry weights of barley tops, grain yields and roots. (SWC 10-d4)

D. Soil Microbiology

1. Decomposition of crop residues. In the 1962 report, results of a laboratory study at Beltsville were reported which showed that when dry soil is stored for long periods of time, there is an increase in readily oxidized carbon and in mineralizable nitrogen. Work is continuing in an attempt to understand the mechanism responsible for this phenomenon. These studies have important implications in dryland fertilizer programs. (SWC 10-aB3)

Incubation experiments at Beltsville with C^{14}-labeled corn roots used as a soil amendment showed that the decomposition of this fresh material reduced the rate of decomposition of the indigenous soil organic matter. When nitrogen was added with the labeled roots, the rate of decomposition increased. However, the rate never did approach that on untreated soil. This retardation of soil organic matter decomposition may be due to a component in the corn root that is toxic to soil micro-organisms. (SWC 10-aB3)

At Lincoln, Nebraska, phytotoxic substances were isolated from stubble-mulched soil using a number of organic solvents. Large quantities of soil were extracted with acetone and fractionated with an activated alumina column. The column was eluted with benzene, ether, ethyl acetate, propanol, methanol, water, 0.1 M formic acid, and 0.1 M sulfuric acid. All fractions contained materials toxic to the growth of wheat seedlings at specific concentrations. Propanol and water fractions contained the highest level of toxicity. Paper chromatography effectively separated two compounds in the propyl fraction which were toxic and gave a positive reaction to ninhydrin. Acidic substances were eluted with sulfuric acid and partial identification of the acids was made by paper chromatography and infrared analysis. (SWC 10-d5)

2. Antibiotics. At Beltsville, detectable levels of the antibiotic terramycin were produced in sterile soil following inoculation with washed spores of the antibiotic-producing organism Streptomyces rimosus. When non-sterile soil was inoculated without alfalfa meal, no antibiotic was detected. If alfalfa meal was applied at a rate of 0.5 percent and the soil inoculated, an antibiotic was produced. These results strengthen the hypothesis that antibiotics are produced naturally in the soil. (SWC 10-aB3)

3. Competition among strains of soybean bacteria. At Beltsville, Maryland, it was found that inoculum applied in currently recommended procedures are of little value when inoculated soybeans are planted in soils which have grown soybeans before and contain organisms capable of producing nodules on these plants. Rhizobial strains were shown to differ greatly in their ability to compete with the established flora in the soil. Strains shown to be highly competitive in a Beltsville soil must be evaluated in other soils, under other climatic conditions and against a changed microflora before a recommendation based on their competitive ability can be made. Hardee, one of the newer soybean varieties, has been shown to be highly specific for strains that will benefit the plant. (SWC 10-36(a3))

4. Modifying bacterial strains. Research was continued on efforts to achieve genetic transformation in Rhizobium, using antibiotic resistance as a genetic marker. Positive evidence of transformation of the factors for resistance to streptomycin and neomycin was obtained in approximately 10 percent of the attempts. The spontaneous occurrence of resistance in the antibiotic-sensitive controls in other tests, however, renders the finding inconclusive. Apparently, the procedures used in developing a state of competence for transformation in the recipient cultures occasionally induce resistance. Until this phenomenon is understood and controlled, it will not be possible to state beyond question that genetic transformation has taken place. (SWC 10-aB6)

5. Rhizobia-induced chlorosis in soybeans. The chlorosis induced in soybeans by certain strains of Rhizobium is associated with the production in the nodules of two unknown amino compounds, one of which is the active

chlorosis-inducing substance. Chemical characterization of this active compound shows it to be a weakly basic, sulfur-containing polypeptide with probably 16 carbon atoms and a suggested molecular weight of 440. The other compound, which may be biosynthetically related to the chlorosis-inducing substance is postulated to be a diamino-monocarboxylic acid with an empirical formula of $C_8H_{20}N_2O_4$. (SWC 10-aB6)

Further work with chlorosis-inducing strains of Rhizobium has shown that, contrary to previous belief, the active substance may be produced by the bacterium in pure culture. The formation of the active compound is dependent upon the composition of the nutrient medium, and the nutritional requirements are different for different strains of the organism. The second amino compound is also produced in pure culture. These findings have made it possible to define the cultural conditions for the large-scale production of this compound by selected strains in culture. (SWC 10-aB6)

6. Inoculation of legumes. Soil samples were collected from 60 fields in the "legume sickness" areas of northeastern Washington and northern Idaho and planted to alfalfa in the greenhouse at Prosser, Washington. Alfalfa on 24 of these soils failed to produce nodules of any kind. Alfalfa growth and appearance on only 22 soils indicated that effective nodules had formed. Using serial dilution techniques, it was shown that about 50 percent of the maximum growth resulted from inoculation with 3,500 organisms per gram of soil. When all nutrients except nitrogen were added, the number of organisms required to effectively nodulate the alfalfa was reduced to 35 per gram of soil. In field studies, fertilization with molybdenum, boron, sulfur, and phosphorus, together with inoculation with effective Rhizobium, markedly increased the growth of alfalfa and proved to be superior to either inoculation or fertilization alone. (SWC 10-f4)

At New Delhi, India, in studies to determine the significance of algae in soil fertility, soil samples were collected from several countries in the Far East and determinations were made of the algae flora. Their results show that the flora was much the same as that found in the rice paddies in India. Work is continuing on the testing of algae as possible nitrogen fixers. (A7-SWC-7)

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AREA 11: SOIL, WATER, AND PLANT RELATIONS AS THEY AFFECT USE OF LAND AND WATER RESOURCES

Problem. Most of the water used in this country is returned to the atmosphere by the process of root absorption and transpiration. Our understanding of the physical, physiological and phenological aspects of the extraction of water from soil by roots, its condensation upward and the manner in which water is lost from the leaves is limited. The productiveness of the soil depends to a large degree on how water moves within the soil. The mechanisms involved in the movement of water in the soil and to the plant root have not been adequately explained and consequently a satisfactory prediction of the behavior of water in soil cannot be made. No basic understanding of naturally occurring field phenomena can be reached until our knowledge of water movement through soils and to plant roots is understood.

The immediate climatic environment around the plant and at the soil surface and the micrometeorological factors which affect these have a profound influence on the growth of the plant, the loss of moisture from the soil and plant and upon the soil itself. These micrometeorological factors offer a means of conserving moisture during the course of plant development. It has been estimated that eighty percent of the sun's energy is used each year to evaporate some 2 million acre-feet of water from plants and soil. The total energy cannot be altered, but it should be possible to divert a greater percentage to use for photosynthesis rather than evaporation.

USDA AND COOPERATIVE PROGRAM

The Division program in this area involves soil physicists, soil chemists, plant physiologists, and engineers in both basic and applied studies. Research to study the relation of the physical properties of soil on the movement of water to and into plant roots is being done at Ithaca, New York; Urbana, Illinois; Columbus, Ohio; Fort Collins, Colorado; Manhattan, Kansas; Big Spring and Weslaco, Texas; Tempe, Arizona; and Riverside, California. Research concerned with the determination of plant-soil-meteorological interactions is being conducted at Ithaca, New York; Watkinsville, Georgia; Thorsby, Alabama; Morris, Minnesota; Urbana, Illinois; Weslaco and Bushland, Texas; Manhattan, Kansas; and Tempe, Arizona. Research for the development of soil and crop management factors for maximum energy conversion is being conducted at Ithaca, New York; Thorsby, Alabama; Morris, Minnesota; Urbana, Illinois; Bushland and Temple, Texas; Manhattan, Kansas; and Tempe, Arizona.

The Division scientific effort devoted to research in this area totals 31.0 professional man-years. Of this number, 14.5 are devoted to relation of the physical properties of the soil on the movement of water to and into plant roots; 12.5 to determination of plant-soil-meteorological interactions; and 4.0 to development of soil and crop management factors for maximum energy conversion.

PROGRAM OF STATE EXPERIMENT STATIONS

Many of the State stations are conducting basic and applied investigations on soil-water-plant relationships. These studies involve agricultural engineers, agronomists, horticulturists, plant physiologists, soil chemists and soil physicists. Frequently a team representing different disciplines work together on individual projects.

In the Northeastern region 9 stations are contributing to regional project NE-48, Soil-Plant-Water Relationships, whose objectives are to study the energy status and dynamics of water in soils and plants, to determine the influence of plant and environmental parameters upon water extraction from the soil profile and to relate physiological conditions in plants to water stress. Investigations are being conducted on the energy required for the movement of water into and through tomato plants subjected to different environmental conditions, effect of high stress on ability of a plant to conduct water, water requirements of asparagus and the ability of the plant to take up water during the cutting season, the extent of transfer of water from one portion of a root system to another where the free energy of the soil water for the two portions of the root system is great, the contribution of water from underlying or surrounding layers to the root zone, and the relation between root attributes to selected forage crops and their capacity to extract water from soil profiles.

In the Western region 8 states and the USDA are cooperating on regional project W-67, Water-Soil-Plant Relations. The objectives of this fundamental project are: (1) to investigate relationships between water stress in root medium and internal water status of plants as affected by environment and plant development; (2) to evaluate effect of plant structures, physiological processes and transpiration retardants on water movement and loss from plants; (3) to determine effects of plant water stress and nutrients on morphology and metabolic processes determining growth and composition of plants; and (4) to seek unification of divergent hypotheses concerning soil water and its effects on plants as a basis for developing concepts leading to more efficient use of water.

Research also is in progress to determine the morphological and physiological responses of trees to soil moisture variables both for newly planted and producing citrus trees, the effects of soil moisture availability on seed germination and seedling development, the differential response of winter

wheat varieties to soil moisture stress and nitrogen availability, the physiological defects of potato tubers as related to moisture availability and root temperatures, the physiological significance of internal water status of plants as measured with beta ray gauging, and the nutritional requirements of cotton under different moisture regimes on selected soils of the Trans-Pecos area.

The total State research effort in this problem area is 42.9 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. The Relation of the Physical Properties of the Soil on the Movement of Water to and into Plant Roots

1. Movement of moisture in the soil. At St. Paul, Minnesota, measuring soil water diffusivity by the transient outflow method in the low water tension range gave unsatisfactory results. The K values obtained with the transient method were lower by several magnitudes than those obtained with the steady state method. Progress is being made, however, in getting a better understanding of soil water diffusivity and in securing some agreement between theory and experimental results. (SWC 11-c1)

At Urbana, Illinois, further proof of the uniqueness of the water capacity function in transient flow systems was obtained. Also, one of the first analyses of a transient flow problem involving hysteresis was obtained. Many investigations had previously been conducted on soil water flow using samples which were initially at a uniform water content. The approach previously used failed to consider hysteresis and a single water content pressure head or tension curve applied to the entire system. In the Urbana study, each level of soil in the vertical column started to wet along a different water content-tension curve. Thus, conditions were more nearly like those found under actual field wetting and drying of soils. (SWC 11-c3)

At Columbus, Ohio, the drainage of peat soils, underlaid with artesian pressure, was examined by use of an electrical resistance network. The data provided information that tile drains needed to be from 40-50 feet apart and that the drain flow rate was primarily a function of drain spacing rather than aquifer pressure. (SWC 11-c3)

Movement of water into, through, and out of the soil is affected by the geometry of the pore space. This is determined to a large extent by the strength of the forces which bind primary particles into aggregates. Studies at Fort Collins, Colorado, indicate that sand can be cemented together into aggregates by alternate wetting and drying. Cementation takes place largely at the soil surface, where most of the silica-saturated solution evaporates. Degree of cementation is a function of particle size

and shape and the number of wetting and drying cycles. Silica solubility of soils and clays increases as sodium saturation increases. In most cases, silica solubility doubled with increase of exchangeable sodium from 20 to 40 percent. These data indicate that part of the silica dissolved in a high sodium soil will be precipitated as it percolates down through layers lower in sodium and higher in calcium. (SWC 11-d1)

A method for determining unsaturated conductivity directly from infiltration data on air dry soils was developed at Brawley, California. The method is based on the difference in the infiltration rate of water into columns of soil placed in vertical and horizontal positions. The difference in vertical and horizontal infiltration is due to the gravitational component and its magnitude was found to be related to the unsaturated conductivity of the soil. The unsaturated conductivity and the soil moisture diffusivity increased with soil moisture content. (SWC 11-13g1)

A new program was initiated at Davis, California, to study transfer processes at a drying front in the soil. Preliminary data indicate that the use of total air pressure as a variable in unsaturated flow experiments will be a useful tool in differentiating between vapor and liquid phase transport of soil moisture. Also, it appears that thermal gradients in quite moist soils could be a significant driving force for water flow. The vapor pressure of the soil moisture film during evaporation is evidently quite dependent upon temperature, amount of dissolved salts, and the moisture content. Water removal from soil is a major factor in all types of agriculture and theoretical advances based on sound experimental data have a potential of being immediately applicable to the solution of existing field problems. (SWC 11-13g1)

Research has continued at Riverside to develop reference data on water characteristics of soil. As often happens in science, refinement in measurements indicate need for refinement in theories. The objective of this project has been to supply realistic reference data on water properties of soil (soil-water retentivity, capacity, diffusivity, and conductivity) for use in combination with present theory to solve field problems. The expected sample-handling advantages of the radial-flow cell have been realized. But instead of serving as a convenient source of the desired data, the cell demonstrates that present theory, or our presently used application of this theory, is inadequate to describe accurately the performance of the cell. (SWC 11-gF1)

It has long been assumed that present theory (Buckingham's law) is but a first approximation, and a first approximation for theoretical solution of field problems could be very helpful. It remains to be seen whether sufficiently realistic values of soil-water properties can be obtained from the water-outflow curves of the radial-flow cell. (SWC 11-gF1)

Some new discoveries have been made at Riverside, California, on the effect of temperature on water transmission in soil. Preliminary measurements indicate that the unsaturated conductivity and diffusivity are strongly temperature-dependent. Reproducibility of the data is not yet satisfactory, but there is little question that both soil properties increase markedly with increasing temperature. This has important consequences with respect to water availability to plants and evaporation from soil. Several different methods of measuring these properties will be used in an attempt to measure them more precisely and to explain their behavior. (SWC 11-gF1)

Simultaneous measurements of tritiated water vapor (THO) and H_2O diffusion in relatively dry Adelanto soil made at the U. S. Water Conservation Laboratory verified the fact that THO cannot be used as a tracer for water movement through partially saturated soils in plant-soil-water systems. The diffusion coefficients of THO and H_2O were different, that of H_2O being consistently, but not proportionally, higher than that of THO at all water contents. A maximum D value of 4×10^{-5} cm.^{2} sec.$^{-1}$ was measured at 2 percent water content for H_2O and 2×10^{-5} cm.^{2} sec.$^{-1}$ at about 3 percent water content for THO. The differences are ascribed primarily to the exchange of the THO tracer molecule with adsorbed H_2O molecule present on the soil surface. (SWC 11-gG1)

Measurement of the relative vapor pressure of water in soils and plants has been refined at the U. S. Salinity Laboratory, Riverside, California. For exploring the elementary mechanisms and processes in the soil-water-salt system, the highest precision attainable for the vapor measurements will be useful. During the past year, attempts were made to decrease the error of vapor measurements below the $\pm$ 0.001 percent relative humidity previously attained. The bath temperature fluctuation was decreased from 10^{-3} to 10^{-4}° C. and the error in measuring the electrical output of the psychrometer was reduced from 10×10^{-9} to 2×10^{-9} volts. Since a hoped for improvement in the precision of the vapor measurement was not attained, it has been tentatively concluded that sample disturbance by water evaporated from the psychrometer may be the dominant measuring error. However, the improvements made in bath temperature control should have numerous applications both for research and for routine service measurements. (SWC 11-gF1)

2. Loss of water from a free water surface. In basic laboratory research at Weslaco, Texas, evaporation and condensation of water were studied as functions of water surface temperature, ambient temperature and relative humidity conditions. Rates ranged from condensation at the rate of 1.6 cm. per day to evaporation at the rate of 4.9 cm. per day. The vapor pressure difference between the water surface and air expressed as a quadratic function explained 99.4 percent of the experimental variation over the entire range of rates encountered. Use of relative humidity, air temperature, and water temperature directly in a regression analysis produced an equation that accounted for 89.7 percent of the experimental variation. The variables relative humidity, ambient temperature, and water surface

temperature accounted for 4, 11, and 76 percent of the total sum of squares, respectively. Thus, temperature of the evaporating surface is indicated to be the variable of most importance in determining the evaporation rate. (SWC 11-e1)

3. Soil crusts. At Auburn, Alabama, the characteristics of soil crust as influenced by particle size distribution and orientation of the particles has been studied. Rainfall-formed crusts had a very fine layer of optically oriented fine particles. At Watkinsville, Georgia, 4-tert-butylpyrocatecol effectively reduced the cohesive strength of crusts. Soil crusting was reduced and seedling emergence increased at Thorsby, Alabama, by the use of fracturing agents, hygroscopic chemicals, water emulsion asphalt, and row direction. (SWC 11-b1)

B. Determination of Plant-Soil-Meteorological Interactions

1. Absorption of radiant energy by soil. At Manhattan, Kansas, the influence of organic matter (soil color) and moisture content on absorption of radiant energy by soil was measured with spectrophotometers. Reflectance--the ratio of the energy reflected to the energy in the incident beam at a particular wavelength--was higher on oxidized than on nontreated samples. The laboratory reflectance measurements were converted to reflected energy curves applicable to field conditions through a spectral energy distribution curve. As an example, the 1.4 percent organic matter of the Newtonia silt loam soil could account for the absorption of 8.2 percent of the energy in the direct solar beam. Additional data collected this year point again to the possibility of using the reflectance method for the determination of soil moisture content. (SWC 11-e1)

Measurements on kaolinite and bentonite clays screened to different particle sizes showed that as particle size increased the reflectance decreased exponentially. Applied to field conditions, increasing the particle size from 22 to 2,680 microns could increase the radiant energy absorption by 14.6 to 20.9 percent of that in the direct solar beam. (SWC 11-e1)

2. Influence of water table depth on transpiration. At Weslaco, Texas, cotton was grown in lysimeters in which water tables were maintained at 3, 6, and 9 feet. Total moisture use (evapotranspiration) consisted of (a) the water used from the water table, (b) moisture depleted from the soil above the water table, and (c) rainfall plus irrigation. As last year, the moisture condition in the root zone and water table depth influenced the proportion of the total moisture use attributable to use from the water table. Moisture use from the water table at 3, 6, and 9 feet was 68.6, 21.5, and 11.9 percent of the total use, respectively, for the high soil moisture condition and 64.3, 44.3, and 23.1 percent, respectively, for the low soil moisture condition. (SWC 11-e1)

3. Techniques for measuring water in the leaf. A quantitative procedure for the selection of radioisotopes for the beta ray gauging of plant leaves was developed at the U. S. Water Conservation Laboratory. Carbon^{14} was calculated to work best for leaf absorber thicknesses of 5 to 20 mg. cm.$^{-2}$, promephium^{147} and technetium^{99} for absorbers of 10 to 40 mg. cm.$^{-2}$, and thallium^{204} from 15 to at least 70 mg. cm.$^{-2}$. The beta ray gauge has been used successfully in water balance studies of cotton plants in which the leaf water content is followed continually under varying environmental conditions. By use of 2 millicuries promephium^{147}, which is normally used in the beta leaf gauge, it was possible to monitor changes which occurred in the stem of the young cotton plant. The data showed that measurable and rapid changes in stem thicknesses occurred during transitions of dark and light periods. (SWC 11-gG1)

At Big Spring, Texas, calibration of a thermocouple psychrometer that utilizes the Peltier effect has been extended to 65 bars suction. Techniques have been devised and an apparatus has been constructed to use the thermocouple psychrometer in measuring the water vapor pressure of plant leaf discs. Preliminary studies and calculations indicate that the thermocouple psychrometer can be adapted for field use. (SWC 11-e1)

4. Stomata activity and transpirations. An investigation at Watkinsville, Georgia, measured reductions in transpiration when stomata were kept closed, in order to evaluate the potential for reducing transpiration by enzymatic control of guard cells. Stomates of several varieties of several species of plants were opened and closed by varying the carbon dioxide concentration in the surrounding air in the growth chamber. Average "observed cuticular" transpiration by corn and sorghum was 32-34 percent and 34-42 percent of total transpiration, respectively. "Observed cuticular" transpiration by cotton, tomatoes and soybeans was somewhat higher: 66-75 percent, 64-79 percent, and 47-66 percent, respectively. Stomatal closure caused an increase in leaf temperature which varied with species. The data indicate that a decided potential exists for increasing moisture conservation through control of transpiration by incorporating those genetic factors responsible for the greater transpiration reductions found in this study. (SWC 11-b2)

An index system was developed at the U. S. Water Conservation Laboratory to express the amount of stomatal opening in numbers from 1 to 10 and it has proven valuable in correlating stomatal opening with transpiration. The index is based on the geometric shape of stomates, as determined with silicone rubber impressions. Studies on plants grown under controlled environmental conditions indicated that the method is helpful in explaining the water-loss behavior of plants during changes in light intensity and atmospheric water vapor deficits. Increases in water-loss rate correlated with increases in the stomatal aperture index and, similarly, water loss decreases to index decreases. (SWC 11-gG1)

Carefully controlled environmental studies carried out at the U. S. Water Conservation Laboratory showed that cotton plants sometimes went through continued 30-minute cycles of alternate wilting and recovery even though all environmental conditions remained constant during the cycling. The cycling occurred when plants went through a night period in an atmosphere with a saturation deficit of 10 millibars. This was followed by an atmosphere with a saturation deficit of 30 to 40 millibars, for about an hour before the plants were subjected to sudden illumination. When the decrease in humidity coincided with exposure to light, the cycling did not occur. (SWC 11-gG1)

In an attempt to chemically control transpiration, two concentrations of phenylmercuric acetate and one concentration of atrazine were sprayed on cotton and grain sorghum plants at 2-week intervals during the plant fruiting period at Big Spring, Texas. Atrazine tended to increase yields of both cotton and grain sorghum and to increase the relative turgidity of cotton. Relative turgidity of grain sorghum leaves was not affected by the chemicals. (SWC 11-e1)

5. Influence of CO_2 on plant growth. Soil aeration and its effect on germination and plant growth have been investigated at Fort Collins, Colorado. Studies have shown that a single critical CO_2 level for growth of plants in soil could not be demonstrated. The kind and extent of CO_2 responses obtained from a given CO_2 treatment depends upon soil moisture suction, O_2 concentration, stage of plant growth, duration of treatment, plant species, and growth variables being measured. The importance of excessive CO_2 as a causal agent of plant injury in conditions associated with deficient soil aeration has probably been overestimated. Corn and soybeans in germination and vegetative growth stages tolerated, and sometimes were stimulated by, CO_2 concentrations in the soil which are usually considered highly toxic to growth. Germinating plants recovered rather quickly from severe CO_2 toxicity upon return to a normal gaseous environment. Both species also tolerated high CO_2 concentrations in their foliar atmosphere. Soybean growth was stimulated markedly by foliar atmosphere CO_2 levels of 3 to 14 percent. Excessive soil moisture, apart from the aeration treatments used, severely limited or completely stopped germinative growth of both plant species. With corn, the effect occurred at soil saturation and was probably due to reduced O_2 diffusion rates. With soybeans, the effect occurred at a lesser soil moisture content than with corn and was due primarily to invasion of seeds and roots by pathogenic organisms. (SWC 11-d1)

6. Influence of soil temperature on plant growth. At Temple, Texas, average height of grain sorghum 24 to 31 days after planting increased 33 percent with an increase in daily average 3-inch soil temperature of 4.9° F., and 51 percent in a treatment where soil temperature at this depth was increased by 6.5° F. Increased soil temperatures early in the season increased seedling growth, phenological development, earliness of harvest, and grain yields. If the soil temperature could be increased a few degrees early in the spring,

the crop could be planted earlier. As a result of early planting and the influence of higher soil temperatures, the plant would develop before the normal dry period of late June and July. (SWC 11-e1)

Temperature measurements made in the soil and plant on June 21 showed that lowering the soil temperature 8° F. at the 3-inch depth lowered stem tissue temperature of corn 5 to 7° F. at a height of 6 inches and 2 to 5° F. at a height of 43 inches. Above ground tissue temperature of grain sorghum was lower for the same soil cooling treatments. (SWC 11-e1)

At Bushland, Texas, soil temperature measurements were made to a depth of 3 feet under dryland and irrigated grain sorghum. The irrigated soil was cooler in the 6- to 36-inch depth interval by a maximum of 4.6 to 7.6° F. The moisture under the dryland plots in 1963 was well above average because of above normal rainfall. (SWC 11-e1)

7. Vertical transfer of energy and gases. At Ithaca, New York, continued studies of energy exchange within an alfalfa, corn, and small grain crop revealed that turbulent diffusion coefficient attenuation with depth into the crop approximately follows an exponential form, depending upon the geometric structure of the plant. (SWC 11-a1)

Two methods were used to quantitatively measure this gaseous exchange coefficient within these crops--an energy balance and a momentum balance. Both methods gave encouragingly close agreement, revealing that turbulent diffusivity values are attenuated exponentially with depth and are several orders of magnitude larger than molecular diffusivity values even near the ground in dense crops. The values of the coefficient, however, depend strongly on the wind speed above the crop and the geometric and elasticity properties of the above ground plant parts. These coefficients in turn influence the patterns and rates of net photosynthesis and transpiration activity by the leaves with a crop. These studies are aimed at finding guides for plant breeding goals and crop management methods for more desired water use efficiency by crops. (SWC 11-a1)

At Urbana, Illinois, laboratory studies showed that soybean leaf hairs significantly reduced wind speed adjacent to the leaf. The study also showed that when the leaf hairs are young and water-filled, they increase transpiration of the leaf by 13 percent, but when the hairs are old and dry, they can reduce transpiration 10-20 percent. Increased transpiration in young, turgid leaves results from the larger surface exposure. This effect more than offsets the benefits derived from reduced wind speed. These results demonstrate that leaf hairs may seriously affect the water economy of plants, especially under drought conditions. (SWC 11-c1)

At Morris, Minnesota, single-row windbreaks of corn placed 40 feet apart in soybeans increased the water-use efficiency by about 0.6 bushels per inch of water used and increased the soybean yields by about 5 bushels per acre.

Although the micrometerological data indicated only small differences in the heat budget resulting from the living windbreak, economic returns would have been increased about $10 per acre. (SWC 11-c2)

The relationships of field-grown cotton to microclimate were investigated at State College, Mississippi. Small but significant effects of vapor pressure deficit and air temperature on the rate of apparent photosynthesis were found at soil moisture tensions less than 0.4 bar. Apparent photosynthesis was related linearly to both light intensity and concentration of atmospheric CO_2. The interaction between these two variables was extremely potent in predicting apparent photosynthesis, and strong indirect evidence was obtained showing that no change in the gas permeability of cotton leaves occurs in response to CO_2 levels in the range of 0-600 parts per million. Increases in transpiration were observed with increasing air temperatures and light intensities. This was attributed to increased stomatal apertures. (SWC 11-b1)

C. Soil and Crop Management Factors for Maximum Energy Conversion

1. Timing of irrigation water. At Weslaco, Texas, 3 years of data show that cotton irrigations can be adequately scheduled according to variations in the relative turgidity of the leaves. Lint cotton yields were closely associated with the longest period of successive days, as well as the total number of days that visible wilting occurred during the bloom stage of plant growth. There were no significant reductions in yields as long as the average relative turgidity of the plant was maintained above the turgidity at which wilting occurs, approximately 72 percent. Yields were significantly lowered as the average relative turgidity dropped below 72 percent. In a companion study in which leaf temperature of cotton was related to leaf relative turgidity, leaf temperature elevation above air temperature at plant height ranged linearly from about 3° C. at 60 percent relative turgidity to 0° C. at 80 percent relative turgidity. (SWC 11-e1)

Comparison of moisture use by cotton on Harlingen clay soil with moisture use by cotton on Willacy fine sandy loam at Weslaco, Texas, shows that on Harlingen clay, moisture extraction was limited to the surface 2 feet of soil due to limited depth of rooting, whereas on Willacy fine sandy loam, cotton was able to efficiently utilize moisture to a depth of 4 feet. Cotton planted in March on Harlingen clay requires 4 to 6 light irrigations spaced every 13 to 15 days, beginning with first bloom, to produce 2 bales per acre. Similar yields can be produced on Willacy fine sandy loam with only one or two irrigations, depending on rainfall, provided moisture conditions are adequate for early spring growth. These results illustrate the tremendous influence depth of rooting has on water management in a given locality. (SWC 11-e1)

2. Influence of soil properties on plant diseases. At Temple, Texas, cotton root rot (Phymatotrichum omnivorum) studies have shown that some soils have

intrinsically higher disease-inducing capacity than others. This soil property is independent of cropping treatment, but is believed to be associated with the type and amount of clay. As little as 2 percent montmorillonite clay in sand will cause a large amount of the disease to form. In contrast, kaolinite exhibits the growth of the fungus at concentrations greater than 1 percent. (SWC 11-e1)

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AREA 12: NUTRITION OF ANIMALS AS AFFECTED BY PROPERTIES AND CHARACTERISTICS OF SOILS AND PLANTS

Problem. Since the beginning of time, man has been concerned with the effects of nutrients in soils upon the nutritional value of various crops. As the sciences of chemistry and nutrition have developed, some understanding of the reasons for the peculiar distribution of certain maladies of humans and animals has been obtained. Mineral nutritional diseases in animals have been recorded in the literature in all but seven states.

In many cases, a lack of a basic understanding of the synthesis and metabolism of nutritionally important substances in plants and animals prevents progress. A basic understanding of the synthesis and metabolism of substances in plants and animals is needed. A knowledge of the functions and pathways of transport of various elements throughout the food chain from soil to plant to animal is required before progress can be made. Soil and climatic areas where the nutritional status of animals and man is affected adversely by qualities of the plant produced need to be identified and characterized. When the relationship among soil properties, climatic factors, and the nutritional quality of plants has been determined, the farmer and rancher can select economic combinations of soil, crop, and livestock management practices that will meet human nutritional needs.

USDA AND COOPERATIVE PROGRAM

This research is centered at the U. S. Plant, Soil and Nutrition Laboratory, a USDA Laboratory located on the campus of Cornell University. Problems in animal nutrition that are prevalent in specific regions are investigated through field surveys in which the incidence of the nutritional problem is related to the composition of forages, types of soil, and other environmental factors. Recent work of this type includes studies of cobalt deficiency in cattle and sheep and on the relationship of selenium in forages to the incidence of muscular dystrophy in livestock. The chemistry of micronutrients in soils is under intensive study in order to develop basic knowledge of factors that influence the micronutrient content of plants. Other investigations are directed toward understanding the functioning of micronutrients in the animal, and the mechanisms invclved in the interactions between micronutrients in animal nutrition. Studies of the site and mechanism of absorption of trace elements in the gastro-intestinal tract are underway. The processes involved in the synthesis and breakdown of nutritionally important compounds in plants and animals are under investigation. One phase of these studies is directed toward the mechanism of formation and metabolism of amino acids and related compounds in plants, with special

attention being directed toward the sulfur containing amino acids. Another phase of this work is concerned with the mechanisms whereby amino acids are linked together to form protein, and the relationship between the molecular structure and the biological function of some of the compounds that play important roles in protein synthesis.

Studies involving large animals are conducted through contracts with State Agricultural Experiment Stations. A contract to investigate the effect of soil applications of selenium upon the incidence of myopathy in sheep is in operation at Oregon State University. Work on the causes of congential malformations in livestock is conducted in cooperation with the Animal Diseases and Parasite Research Division at Logan, Utah.

The Federal scientific effort devoted to research in this area totals 15 professional man-years. Of this number, 3.3 are working to characterize soil and climatic areas where the nutritional status of animals and man is affected adversely by quality of plants produced; 3.9 are devoted to basic understanding of the synthesis and metabolism of nutritionally important substances in plants and animals; 2.8 to biological assays of plant material grown under different soil, geological and other environmental conditions to nutritional disorders in animals and man; and 5.0 to elaboration by plants of vitamins, amino acids, proteins, and other organic nutrient compounds required by animals. The Soil Conservation Service maintains a full time scientist at the Plant, Soil and Nutrition Laboratory for studies relating nutritional problems to specific kinds of soil.

PROGRAM OF STATE EXPERIMENT STATIONS

Soil and climatic factors which influence plant composition so that livestock which feed upon these plants develop toxic, deficiency or unthrifty conditions are being characterized. The problems are sometimes mineral deficiencies such as cobalt, copper, selenium, and iodine; sometimes it is an excess such as molybdenum or selenium and sometimes the production of toxic level of such factors as oxalates and hydrocyanic acid. Proper supplementation to overcome the deficiencies and management to prevent damage from the excesses are being investigated.

Studies are being made to develop an understanding of the fundamental soil factors influencing the synthesis of nutritionally important substances such as vitamins, proteins, carbohydrates and other nutrients and the plant content of nutritionally important minerals.

The need to know nutrient deficiencies or excesses in feeds in order to develop a suitable ration or feeding plan is receiving consideration in the development of biological assay methods for the rapid determination of such nutrient deficiencies or excesses. These methods will provide needed information to identify the soil, geological and other factors which contribute to nutritional disorders of man and animals.

The total State agricultural experiment station effort in this problem area is 10.8[1/] professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Soil and Plant Composition as Factors Affecting the Distribution of Nutritional Problems in Livestock

1. Selenum. Studies of soil and plant composition as factors affecting the geographic distribution of white muscle disease (a type of muscular dystrophy) in lambs and calves have been continued. The finding, first reported last year, that regions where white muscle disease is common are characterized by universally low Se concentrations in the locally produced forage crops has been substantiated by additional studies of samples from northern California and southern Florida. These areas, like others where white muscle disease is common, are producing forages containing less than 0.1 ppm. of Se. The average Se content of all forage samples obtained from areas where white muscle disease is common is less than 0.06 ppm. Se, for over 50 samples measured. However, within any area where white muscle disease is common, there does not appear to be any significant difference in the Se content of the forages on the individual farms where this disease has been a problem, when compared to the Se content of forages on farms that have not experienced this trouble. It is felt that the farm-to-farm occurrence of white muscle disease within these areas is due to differences in the levels of vitamin E, or unidentified inhibitors to Se, or vitamin E action in the livestock ration, or to differences in stress on the animals. Soil factors, as reflected in the Se content of plants are of primary importance in the broad regional patterns, rather than the farm-to-farm occurrence, of white muscle disease. (SWC 12-aA1)

Experiments to determine whether or not Se could be added to the soil and be taken up by forage plants in sufficient amounts to protect animals from white muscle disease are being conducted in cooperation with the Oregon Agricultural Experiment Station and the Cornell University Animal Husbandry Department. In one of these experiments, beds of soil, 6' x 16' in size, were placed in the Laboratory greenhouse and planted to alfalfa. After the

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[1/] Also reported in Animal Science

alfalfa was established, the beds were fertilized with Se and sulfur in various combinations. Alfalfa produced with these treatments is being fed to chicks to determine the biological value of the Se contained in it, as compared to Se added to the diet as inorganic selenite. Tentative results indicate that the Se in alfalfa is effective in the prevention of exudative diathesis, a Se-responsive complaint in chicks. For unit of Se, the Se in alfalfa is apparently slightly less effective than inorganic selenite. (SWC 12-aA3c)

In Oregon, alfalfa hay produced on a Se-fertilized field area is being fed to ewes during the gestation period, in comparison with alfalfa produced on an unfertilized area of the same field. The unfertilized area produced hay containing less than 0.04 ppm. Se, while the alfalfa from the fertilized area contained 2.7 ppm. Se. This sharp difference in Se contents of the fertilized and unfertilized hays should provide a definite test of the possibility of using Se in fertilizers to prevent the Se-responsive diseases. (SWC 12-aA3c)

One of the major problems that will require solution if selenized fertilizers are ever to become practical is the danger of creating forages containing toxic levels of Se. In the work described above, the Se has been added to the soil as a water solution of sodium selenite. Using this technique, the Se content of forages produced has been quite variable, ranging from 0.6 ppm. to 10 ppm. for applications of 1 pound of Se per acre to various soils under field and greenhouse conditions. In order to develop methods of Se fertilization that would give less variable results as far as Se content of the plants is concerned, and a greater margin of safety from Se toxicity, some experimental selenized superphosphate fertilizers prepared by the U. S. Fertilizer Laboratory have been studied in the greenhouse. These materials have shown promise in that they result in lower and less variable Se content in plants than do applications of sodium selenite solutions. At the present time, one of these selenized superphosphates, tagged with radioactive Se, is being studied on a variety of different soils. (SWC 12-aA2)

One step necessary to the conduct of these investigations of Se in soils and plants has been to develop reliable chemical methods for measuring the very low concentrations of Se found in plants, animal tissues, milk, soil extracts, etc. During the past year, a method based upon measurement of Se concentrations by measuring the fluorescence of a compound formed by reacting the Se with 2,3-diaminonapthalene (DAN) has been perfected. This method is very sensitive and gives excellent agreement with procedures based upon neutron activation. (SWC 12-aA1)

2. The "monkey face" congenital abnormality in lambs. Studies of the effect of the range plant, Veratrum californicum, upon congenital abnormalities in lambs have been continued in cooperation with the ADP Poisonous Plant project at Logan, Utah. The work done at this Laboratory has consisted of

determining the effect of veratrum collected from different locations, and of various fractions of the veratrum plant upon gestation in rats. In order to avoid difficulties due to the low-palatability of diets containing veratrum, suspensions of the finely ground plant material or extracts of veratrum were administered to the female rats by a stomach tube technique. By means of this technique, it was established that veratrum collections from different sites varied in their effect upon gestation in the rat. A collection made in the Raft River Mountains of Boxelder County, Utah, was especially damaging to the gestation process. When this collection was administered to the dams at day ten of the gestation period, toxic symptoms lasting two or three days resulted; the weights of the embryos produced was decreased, frequent resorptions occurred, and some deformities of the fetus were evidenced. Much less toxicity was evidenced from collections of veratrum made at three other sites in Idaho and Utah, and by Veratrum viride, a related plant common in the northeastern states. (SWC 12-aA1)

A benzene extract from the Boxelder County veratrum, lyophilized and redissolved in corn oil, and administered to rats by stomach tube, resulted in damaging effects similar to those shown by the whole plant suspension. The damaging effects of the benzene extract disappeared if the extract was permitted to stand exposed to the air for several days. This indicates that the toxic substance is probably an organic compound subject to destruction by air oxidation. A similar conclusion can be based upon the finding, reported earlier, that the toxicity of veratrum collections decreased during storage at room temperature. (SWC 12-aA1)

The different collections of veratrum, varying in their toxicity to rats, were examined for their trace mineral content by X-ray fluorescence spectroscopy. No differences in trace mineral content, that could be related to differences in effect upon gestation in the rat, were detected by this technique. (SWC 12-aA1)

The same collections of veratrum that were tested on rats at the U. S. Plant, Soil and Nutrition Laboratory were also tested on ewes by Dr. Binns and his group at Logan, Utah. From his work, it appears that veratrum contains a factor or group of factors that give rise to toxic symptoms such as excessive salivation and uncoordinated movements, immediately after administration to ewes, and a factor or group of factors that cause malformations in the lambs born to these ewes. From a cross-checking of the results with sheep and rats, it appears that the effects of any one collection of veratrum upon rats correspond more closely to its effect upon immediate toxicity in ewes than to the effects upon malformation in the lambs. Thus, the rat experiments assay primarily for the toxic factor or factors, rather than for the teratogenic factor or factors, and rat experiments may have limitations as a technique for studying the factors causing the malformed lambs. (SWC 12-aA1)

An analysis of all of the work done on this problem over the last six or seven years suggests that the toxic and teratogenic factors are labile organic compounds, and that the mineral composition of the plant is not a factor in the effect of veratrum upon the fetus. Collections made from soils developed from granite, basalt, and limestone have all produced deformed lambs in some years. Similarly, collections made from both well drained and poorly drained sites have produced the malformations. There is a variation from year to year in the relative toxicity of veratrum from different sites. In view of the findings of the group at Logan that the timing of foetal injury from veratrum is very critical to the incidence of malformed lambs, it appears that the unique concentration of the malformed lamb problem in certain areas is due to a coincidence of the timing of the gestation period of the ewes with their exposure to veratrum in the area where they are grazing. (SWC 12-aA1)

3. Distribution of nutritional problems in livestock in relation to soils.

Three general areas of Mo-induced Cu deficiency have been recognized in Oregon through cooperative studies with the Soil Conservation Service and the Oregon Agricultural Experiment Stations. The general areas are in northwestern Oregon in the vicinity of Astoria, the lower Klamath area, and Baker Valley. In the three areas, there are wet soils that produce legumes with 10 ppm. or more Mo. Forage with 10 ppm. Mo or more is considered toxic when grazed by sheep and cattle under Oregon conditions. The well-drained soils in each of the areas have about the same amount of soil Mo (1.0 ppm. or more), but the Mo content of the legume is not high. The Cu content of 5 to 8 ppm. or more in the legumes from the wet soils does not differ significantly from those of the well-drained soils. (SWC 12-aA1)

In northwestern Oregon, extensive areas of the wet Mo-problem soils are found along the floodplain of the Walluski River, on the floodplain at the confluence of the Walluski and Youngs Rivers, and along the wet lowlands of the Columbia River. The source of the Mo appears to be the sedimentary rocks that cap the Columbia River basalt. It is not known whether the Mo is from the sedimentary rocks (non-marine) of the Pliocene or from the marine sedimentary rock of the Miocene age. Sedimentary rocks generally are reported to vary widely in Mo content between strata and from one area to another. It is significant to point out that poorly drained, silty soils similar to those that produce high Mo forage on the floodplains of the Columbia River also occur on Sauvie Island. These soils on Sauvie Island are low (0.5 ppm. or less) in total Mo and grow legumes containing low amounts of Mo. This difference is apparently due to a greater portion of sediments carried down by the Columbia River to Sauvie Island, in contrast to sediments moved from adjacent highlands to areas where the soils produce forages high in Mo. (SWC 12-aA1)

In the lower Klamath area of southern Oregon, Mo-problem soils appear to be the Keno and Keno-like soils, and mucks and peat soils associated with them. This is a wet, marshy area of diatomaceous earth sediments. Not all the wet soils in this general area produce forages that are high in Mo, but the wet soils that produce low Mo forages are formed from a greater mixture of sedimentary materials than are the Keno soils. (SWC 12-aA1)

In the Baker area of eastern Oregon, critical areas of Mo-problem soils occur along some of the eastward flowing tributaries of the Powder River. The source of the soil Mo appears to be the granitic intrusive rocks of the Wallawa Mountains. The wet soils along the floodplain of Hot Creek and Willow Creek in particular have large amounts of soil Mo (2.5 to 4.0 ppm.), and clovers from these soil sites have from 40 to 60 ppm. Mo. (SWC 12-aA1)

Contrary to some earlier results, Co deficiency in ruminants does not appear to be a major problem in Oregon. The Co content of Oregon legumes with very few exceptions was greater than 0.07 ppm., and the amount of soil Co, even in the sandy soils, was large. The general adequacy of Co, indicated by the nearly 800 forage analyses of samples from 300 soil sites, are consistent with results of a more recent animal trial with the Co bullet technique undertaken by animal scientists of the Oregon Agricultural Experiment Station. (SWC 12-aA1)

The Cu contents of legumes and grasses from agriculturally important soils of the New England States were determined in a cooperative study with the Soil Conservation Service. Cases of Cu deficiency in livestock are not known to occur in this area, although a number of legume samples were found with low Cu contents. (SWC 12-aA1)

The Cu content in legumes increased with Co content. The legumes that met the minimum Co requirement of 9.07 ppm. Co tended to have about 7.0 ppm. Cu. The Co content of grasses tended to be low, irrespective of Cu content. (SWC 12-aA1)

The tendency of the Cu contents to change with Co tended to associate the soils producing low Cu forages with the areas producing forages of low Co content, previously reported. There were 42 soil sites where the Cu content of legumes was less than 6 ppm. These sites occurred principally along the coast of Maine, New Hampshire, and Massachusetts. The mean Cu content was 4.3 ppm. in legumes and 3.6 ppm. in grasses from the 42 soil sites. Unlike the low Co areas, however, soils that grow legumes with 6 ppm. or less Cu were sporadically distributed and were not contiguous. (SWC 12-aA1)

The soils formed in granitic drift deposits along the Merrimac and Pemigawasett Rivers of New Hampshire appear to have inherited low amounts of Cu as well as of Co. The granitic soils here had an average total Cu content of 8.9 ppm. The soil Cu content was less than one-half of the average Cu

content of granitic soils (19.8 ppm.) and about one-third of the average Cu content (25.8 ppm.) of all soils of the New England States studied. (SWC 12-aA1)

B. Trace Element Functions and Interactions in Animal Nutrition

1. The mechanism of bone formation. Research conducted to investigate the role of trace elements in bone formation has been continued. These investigations have been expanded to include a study of the biochemical, histochemical, and enzymatic changes which take place in the bones of chicks suffering from three types of bone deformities; perosis (trace element deficiency), rickets (calcium and phosphorus deficiency), and metaphyseal ischemia (cause unknown). This approach has provided; (1) information leading to a better understanding of the metabolic processes involved in bone formation, and (2) a strong diagnostic tool for the identification of bone deformities of unknown etiology. (SWC 12-aA8)

Metaphyseal ischemia, previously referred to as a rickets-like syndrome, has received considerable attention. Although gross examination suggests an ephyseal cartilage abnormality similar to rickets, histological studies have demonstrated that this abnormality does not resemble the histological lesions produced by many of the nutrients known to affect bone formation, such as--calcium, phosphorus, vitamin D, manganese, zinc, choline, niacin, folic acid, biotin, or vitamin A. The ischemia histological lesion is characterized by the accumulation of mature chondrocytes having atypical nuclei accompanied by the complete lack of penetration by the blood vessels from the metaphysis. In addition, the extracellular matrix lacks the neutral polysaccharides which are present in normal bone. (SWC 12-aA8)

As noted previously, the incidence of this abnormality is influenced by nutrition and the genetic constitution of the chick. In cooperation with Cornell University, two strains of chicks have been developed; one with an incidence of more than 50 percent, a second with an incidence of less than 15 percent. The syndrome also appears to be sex-linked or sex-influenced, since the frequency of occurrence is considerably higher in male chicks. (SWC 12-aA8)

Attempts to identify the nutritional factor or factors involved in the production of the syndrome have been unsuccessful. This abnormality occurs in chicks fed a purified diet which satisfies all the known nutritional requirements of the young chick. Metaphyseal ischemia can be prevented by feeding young chicks a diet composed of practical ingredients. Testing individual components of this diet has shown that many materials afford partial protection but none completely prevent the occurrence of the abnormality. Likewise, the ash of the practical diet and many divalent cations also afford partial protection. However, these cations are fed in excess of the dietary requirements for these nutrients. (SWC 12-aA8)

The influence of age on the development of this syndrome has also been investigated. This was of interest since there are certain similarities between the histological lesion and embryonic bone. Experiments have shown that the maximum development of this abnormality occurs between the second and fourth week of age. Thus, it would appear that the occurrence of metaphyseal ischemia bears little relationship to embryonic bone. (SWC 12-aA8)

2. The "crooked calf" abnormality. For several years, this Laboratory, in cooperation with the ADP Poisonous Plant project at Logan, Utah, has been investigating a problem called "crooked calf." This problem occurs in several range areas in western United States. The abnormality is a congenital deformation of the neck and front legs of calves, and the bones of the deformed calves show certain gross similarities to the bone defect known as "perosis" in chicks. There is some evidence that the ingestion of blue lupine by the pregnant cow during the early stages of gestation may give rise to this defect in the calves, and combinations of lupine and lead, fed to pregnant heifers under controlled conditions, have resulted in the birth of calves with defects similar to those shown by field cases of "crooked calf." More recently, workers at the Washington Experiment Station have found that cows fed low levels of manganese give birth to calves showing similar defects. Because of these findings, an experiment was conducted to determine whether or not there was a metabolic interaction between lupine and manganese. (SWC 12-aA1)

The effect of manganese deficiency in causing perosis in chicks was utilized as the basis for a bioassay of the effects of lupine on the availability of manganese. Chicks were grown using a diet that contained a marginal level (7.5 ppm.) of manganese and also on a diet with abundant (100 ppm.) manganese. Part of the chicks on each diet were also supplemented with 5 percent lupine. The addition of lupine to these diets had no apparent effect upon the utilization of manganese in the chick--in fact, it appeared that the manganese contained in the lupine was of value to the chicks on the low manganese diet. The results of this experiment indicate that the effect, if any, of lupine in the development of the "crooked calves" is not due to an interference by lupine upon the availability or metabolic functioning of manganese. (SWC 12-aA1)

3. The site of absorption of micronutrients. Studies have recently been initiated to learn more of the sites of and mechanisms for the absorption and retention of several nutritionally important mineral ions. To date, this work has been concerned primarily with the in vivo absorption of Cu^{64} and Zn^{65} from ligated segments of the gastrointestinal tract. Preliminary results indicate that the rate of absorption of Cu^{64} decreases as it descends the gastrointestinal tract from the stomach to the ileal position of the small intestine. In contrast, Zn^{65} is absorbed most rapidly from the duodenum, to a somewhat lesser degree from the middle and ileal sections of the small intestine and negligibly from the stomach. (SWC 12-aA3c)

4. Copper-sulfur-molybdenum interactions in animal nutrition. In cooperation with the Biochemistry Department of Cornell University, a detailed study of the effects of molybdenum and sulfur upon the copper nutrition of animals and the storage of copper in the liver has been conducted, using white rats as the experimental animal. This study demonstrates that the initial copper status of the animal and the level of copper in the diet are of primary importance in determining the type of interactions that take place among copper, sulfur, and molybdenum. If the copper reserves of the animal are low, a relatively low level (10 ppm.) of dietary molybdenum will precipitate the symptoms of copper deficiency. These are poor growth, anemia, and diarrhea. The addition of sulfate, along with the molybdenum, intensified these symptoms of copper deficiency. The addition of extra methionine to the diet of copper-deficient rats also decreased growth. Addition of copper (at 3 ppm.) corrected the anemia and diarrhea. In copper-depleted rats, on diets with no added copper, molybdenum or methionine reduced the concentration of copper in the liver. Sulfate had no effect on liver copper in these animals. (SWC 12-aA3c)

On the other hand, when animals having adequate supplies of stored and dietary copper were studied, the addition of molybdenum to the diet had markedly different effects. In these copper-adequate animals, molybdenum toxicity appeared only at high levels (800 ppm.), and this toxicity was evidenced only by retarded growth--anemia and diarrhea did not appear. The addition of sulfate and methionine improved the growth of the rats on adequate copper plus high molybdenum diets. Under conditions of adequate copper, the addition of molybdenum to diets increased liver copper stores. Low levels of sulfate, or sulfur equivalent levels of methionine, tended to counteract the effect of molybdenum in increasing copper stores, but high levels of added sulfate were ineffective in this respect. (SWC 12-aA3c)

An additional group of rats with adequate liver stores of copper was fed a diet containing a very high level (300 ppm.) of added copper. At this excessively high level of copper nutrition, molybdenum and molybdenum plus methionine decreased liver copper accumulation, and sulfates did not modify the effects of molybdenum on liver copper stores. (SWC 12-aA3c)

These experiments indicate that molybdenum toxicity, under conditions of "normal" copper stores and adequate dietary copper, is an entirely different problem than the molybdenum toxicity observed when animals with depleted liver copper stores are fed molybdenum in low copper rations. It appears that the molybdenum toxicity noted in cattle and sheep in certain areas of western United States is a molybdenum-copper interaction of the type noted in the copper-deficient animals on these experiments. The molybdenum toxicity noted in copper-adequate situations does not appear to be a molybdenum-copper interaction. (SEC 12-aA3c)

Furthermore, measurements of liver copper stores, either by biopsy or post mortem techniques, are not always indicative of the true copper status of the animal. These measurements can be accurately interpreted only with reference to the levels of copper, molybdenum, sulfates, sulfur amino acids, and perhaps other constituents of the diet. (SWC 12-aA3c)

5. X-ray fluorescence methods of animal nutrition studies. An X-ray spectrographic method for the determination of chromic oxide in dried ground manure has been developed in cooperation with the Crops Research Division, ARS, and Cornell University. Chromic oxide is a nonreactive mineral tracer commonly used to measure feed consumption in animal feeding trials. The proposed method appears suitable for the rapid and accurate determination of chromic oxide in dried ground manure. (SWC 12-aA2)

The reference curve for the determination of the chromic oxide concentration is based on a set of samples analyzed chemically. The counting rate at the chromium K alpha line is plotted as a function of the chromic oxide concentration. In working out this technique, it was found that standard samples prepared by mechanically mixing varied amounts of chromic oxide with dried ground manure were not satisfactory. (SWC 12-aA2)

Zinc deficiency in pigs gives rise to an illness called parakeratosis. Studies of this nutritional problem require methods of measuring the mammary transfer of zinc from the dams to the young pigs. A procedure was developed for the X-ray spectrographic determination of zinc in dried powdered sow's milk. The powdered milk was prepared by freeze-drying and was mounted loosely on 0.05-inch thick frames. The zinc concentration ranged from 20 to 60 ppm. in the dry powdered milk from sows fed different levels of zinc. (SWC 12-aA3c)

The reference curve for the determination of the zinc concentration is based on a set of reference samples prepared by adding increments of zinc in an aqueous solution to liquid sow's milk and freeze-drying the resulting mixture. A linear curve is obtained when the ratio of the counting rate at the zinc K alpha line to the counting rate at the background is plotted as a function of the zinc concentration. (SWC 12-aA3c)

C. Biosynthesis of Amino Acids, Peptides, and Proteins.

1. The soluble ribonucleic acids in protein synthesis. Studies of the intermediate chemical processes in the biosynthesis of proteins have been continued in cooperation with the Department of Biochemistry of Cornell University. Work during the year has been concerned chiefly with further studies of the structures of the alanine-, tyrosine-, and valine-specific soluble ribonucleic acids (RNA's) of yeast. In the yeast cells, the RNA's carry their specific amino acids to the site of protein synthesis. They are long chain molecules, approximately 75 nucleotides in length, and each RNA is composed of four different major nucleotides, plus several minor or

unusual nucleotides. Most of the work during the year has been concerned with the identification of additional unusual nucleotides, and identification of short oligonucleotide sequences obtained by enzymatic digestion. The long run objective is the determination of the complete nucleotide sequences of the RNA's. (SWC 12-aA4)

Specific accomplishments during the year include discovery of a new unusual nucleotide in the alanine RNA, identification of an unusual tetranucleotide sequence in all the RNA's and determination of the sequence of an octanucleotide, which is the largest oligonucleotide that has been obtained from any purified RNA. The new unusual nucleotide, 1-methylinosinic acid, is readily destroyed in alkali and can easily be overlooked in standard methods of nucleotide analysis. It is found in the alanine RNA adjacent to pseudouridylic acid. The unusual tetranucleotide, which contains both ribothymidylic acid and pseudouridylic acid, has been found in all the purified RNA's, as well as in crude yeast, E. coli, and liver soluble RNA. Its general occurrence suggests that it may occupy a specific position in the structure of all soluble RNA's and may play an important role in the activity of the molecules. The sequence of the octanucleotide obtained from the alanine RNA has been established by partial enzymatic degradation followed by fractionation and analysis of the products. (SWC 12-aA4)

As a result of these fractionation and identification studies, nearly all of the approximately 75 nucleotides present in the alanine RNA have been accounted for in both pancreatic ribonuclease and takadiastase T1 ribonuclease digests of the RNA. Combination of the results of the analyses of the two enzymatic digests makes it possible to describe the molecule in sixteen oligonucleotide sequences. Considerable work remains in making the analyses quantitative, and the order in which these sixteen sequences occur remains to be established. (SEC 12-aA4)

Further studies on the fractionation of the E. coli soluble RNA's by extended countercurrent distribution have established that there are at least five different leucine-specific RNA's. The different leucine RNA's are responsible for the observation that different synthetic polynucleotides stimulate the incorporation of leucine into protein. Extensive countercurrent distribution studies of other soluble RNA's suggest that there is more than one soluble RNA for most amino acids. (SWC 12-aA4)

2. The synthesis and metabolism of amino acids and peptides. In previous years, several γ-glutamyl peptides have been identified in plants at this Laboratory. Because some of these occur in relatively high amounts, experiments have been conducted on the utilization of these peptides, using the chick for the test. A quantity of γ-glutamyl-phenylalanine was synthesized and fed to chicks on a phenylalanine-deficient diet. The almost equal growth of the chicks on the peptide in comparison with an equivalent amount of phenylalanine clearly indicated that chicks can hydrolyze γ-glutamyl peptides. Further work with cell-free preparations of chick kidneys revealed

the presence of an enzyme capable of hydrolyzing γ-glutayml-phenylalanine. Hence, chicks have the ability to utilize γ-glutayml peptides and, apparently, as a result of simple hydrolysis of the peptide. (SWC 12-aA7)

A previously unidentified amino acid has been isolated from jack bean seeds and identified as L-α-amino-δ-hydroxyvaleric acid. This is an extremely interesting finding because of the obvious close chemical relationship between this and glutamic semialdehyde, proline, and ornithine. Studies are underway to learn about the metabolism of this amino acid. (SWC 12-aA7)

Some of these studies have been conducted in an attempt to determine the role of L-α-amino-δ-hydroxyvaleric acid (DAV) in the amino acid metabolism of the young chick. Interest in this compound was aroused by the discovery of a report by some Canadian scientists that DAV stimulated the growth rate of chicks fed an arginine-deficient casein diet. These workers suggested that DAV was in some way substituting for arginine in the nutrition and metabolism of the young chick. This suggestion was of considerable interest since the chick differs from many other species of life in that it cannot synthesize arginine from ornithine, a close relative of DAV. Secondly, chicks require considerably more arginine when fed diets containing casein as a source of protein than when fed diets containing other sources of protein or diets composed of free amino acids. This effect is thought to be due to the unusual amino acid composition of casein. (SWC 12-aA7)

Our experiments have demonstrated that chicks will respond to DAV when fed arginine-deficient diets, with casein or free amino acids simulating casein as a source of protein. No response is obtained when DAV is added to a regular free amino acid diet deficient in arginine. Thus, it would appear that the response to DAV is in some way related to the effect of casein upon the arginine requirement. A subsequent experiment using a free amino acid diet simulating casein has shown that arginine-deficient chicks respond to glutamic acid as well as DAV. There was no response to DAV in the presence of glutamic acid. Furthermore, glutamic acid had no effect in the presence of adequate levels of arginine. Since the response to DAV and glutamic acid was not additive, it appears that the response to these substances occurs via some common pathway. Secondly, the response to these compounds seems to be associated with the increased need for arginine which occurs with diets having the casein amino acid pattern. (SWC 12-aA7)

Extensive work has been done on the metabolism of S-methyl-cysteine, a sulfur amino acid closely related to methionine and cysteine. Initial studies on the synthesis of methylcysteine in kidney bean leaves was reported last year. Since that time, it has been established that radish leaves are far better for studies of methylcysteine biosynthesis. By administration of various radioactive compounds to radish leaves, there are strong indications that methylcysteine is formed by the transfer of a methyl group from

methionine to cysteine. Further work has been done with inhibitors to try to elucidate a possible mechanism. At this time, these results are inconclusive, but it appears possible that S-adenosyl methionine is an intermediate. (SWC 12-aA7)

Other work has involved the transformation of methylcysteine to other compounds. Studies of non-oxidative metabolism of methylcysteine in kidney bean leaves has demonstrated a facile transfer of the methyl group to methionine. Work of others with Neurospora had previously suggested that methylcysteine might be an obligatory precursor of methionine. The results with kidney bean cannot yet be so interpreted, but indicate the desirability of further work along this line. (SWC 12-aA7)

In collaboration with the Botany Department at Cornell, the oxidative metabolism of S-methylcysteine has been investigated. Specifically, the oxidation of methylcysteine to its sulfoxide has been accomplished in cell-free preparations. This is significant because this is the first time that a cell-free system for the formation of naturally-occurring sulfoxides has been obtained. The enzyme is associated with the microsomes and requires reduced triphospho-pyridine-nucleotide and gaseous oxygen. This system will be purified and characterized since oxygen-activating enzymes are uncommon and are often unique. (SWC 12-aA7)

There are a number of other sulfoxides which normally occur in plants, and these are probably formed in an analogous fashion to methylcysteine sulfoxide. Hence, it is likely that it will be relatively easy to learn how other sulfoxides are formed from our understanding of the methylcysteine oxidase system. Since most of naturally-occurring sulfoxides are involved in the development of flavor and odor in plants, and since many are present in relatively large amounts, a knowledge of their formation is worthwhile. (SWC 12-aA7)

Several years ago, two new aromatic dicarboxylic acids were isolated and identified in this Laboratory. These are m-carboxy-phenylalanine and m-carboxyphenylglycine. Because of their obvious close chemical relationship to the protein amino acids, phenylalanine, and tyrosine, studies were initiated to learn whether there was any metabolic connection between the mono- and dicarboxylic aromatic amino acids. The aim was to learn more about the formation of phenylalanine and tyrosine. Radioactive m-carboxyphenyl-alanine was synthesized and fed to leaves. The uncombined amino acids were extracted from the leaves, the amino acid separated by paper chromatography, and counted. Out of the number of possible interconversions sought, the only clear cut one was the derivation of m-carboxyphenylglycine from m-carboxyphenylalanine. (SWC 12-aA7)

D. Chemistry of Micronutrients in Soils

1. Organic complexes of heavy metals in soils. Procedures were developed over the past year for estimating the proportion of certain heavy metals that occur in soil solution as complexes. A competing complexing agent that forms an extractable complex with the metal is introduced into the soil solution system along with an organic solvent. The competition between the added and native complexing agents, as measured by the distribution of the metal between aqueous and organic phases, is used to deduce the fraction of the metal complexed by the native ligands. In this way, methods for estimating the native complexing of Co and Zn have been developed and evaluated, while methods for Cu are in the process of evaluation. Results with these methods on soil solutions from arable and forest soils of New York State indicate that Co is rarely complexed to any significant degree. Zn is complexed in most soils but rarely more than 50 percent. Preliminary results with Cu indicate complexing plays an important role in the chemistry of this element in most soil solutions. As much as 99 percent of the Cu was complexed in certain forest soils. (SWC 12-aA5)

Preliminary characterization of one of the soil solutions indicates that two types of complexing agents predominate. One is weak acid, the other a strong acid. Attempts are now underway to separate and further characterize the complexing agents involved. (SWC 12-aA5)

In connection with the above project, a new analytical procedure was adapted to the determination of Cu in biological systems. It is a colorimetric procedure using diphenylcarbazone in benzene. It is about ten times as sensitive as the diethyl dithiocarbamate procedure. (SWC 12-aA5)

Root exudate studies mentioned in last year's report were for the most part deferred until methods were developed for the characterization of soil solution. However, solubility studies and titration curves were used to show that root exudates of radish significantly complex Cu and Zn. (SWC 12-aA5)

2. The effect of soil moisture level on the availability to plants of iron, manganese, and zinc. The role of soil moisture conditions on the availability of Mn, Fe, and Zn was investigated in a field and greenhouse study to determine the magnitude and direction of changes of the micronutrient availability with changes in moisture levels in soils. (SWC 12-aA2)

Under greenhouse conditions, the concentration of Mn and Fe in the soil solution and in alsike clover of two Brown Podzolic soils was higher for a wet soil treatment (water table at 7 inches depth) than for the same soil maintained at a low moisture level (0.2 atmospheres suction to plant wilting). The concentration of soil solution Mn and Fe of a Brown soil and a Wiesenboden soil of Nevada was also greater in the wet soils, but the increases were not reflected in increased Mn and Fe concentrations in alsike clover. Unlike Mn and Fe, the Zn concentration in the soil solution and in alsike clover tended to decrease with soil wetness. (SWC 12-aA2)

Under field conditions of varied soil drainage, the Mn, Fe, and Zn contents in legumes of the well-drained soils did not differ from those of the poorly drained soils on lower, downslope positions of the same slope. The Mn, Fe, and Zn contents, moreover, were nearly the same in legumes from coarse-textured, granitic alluvium and from heavy-textured lacustrine soils. (SWC 12-aA2)

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AREA 13: FERTILIZER TECHNOLOGY INVESTIGATIONS, RESOURCES, PRODUCTION, AND IMPROVEMENT

Problem. In a rapidly shifting agricultural economy, fertilizers must be fitted to the changing needs if the farmer is to realize maximal returns for each dollar invested in fertilizer and protect his profits against inevitable rising costs. Manufacturing procedures, insofar as they influence nutrient content, nutrient quality, and physical character of the fertilizer, must be aligned with use benefits in order to permit the design of products that are fully adapted to the service requirements of different crops under particular management practices.

USDA AND COOPERATIVE PROGRAM

The Division has a continuing long-term program at Beltsville, Maryland, involving inorganic and physical chemists, a soil scientist, a commodity analyst, and a chemical engineer engaged in basic chemical and physical studies and the application of known principles to the solution of fertilizer problems in the factory and in field distribution.

The Division scientific effort devoted to research in this area totals 25.0 professional man-years. Of this number, 11.0 are devoted to materials development and refinement; 5.0 to mixed-fertilizer investigations; 6.0 to standardization of specifications and test procedures for marketed fertilizers; 0.0 to agricultural chemical additives; and 3.0 to consumption trends and use patterns.

PROGRAM OF STATE EXPERIMENT STATIONS

Most of the State experiment stations have small fertilizer research programs. Most of the stations are cooperating with USDA, Tennessee Valley Authority and the fertilizer industry in evaluating new fertilizer materials in laboratory, greenhouse and field experiments. For example, the Mississippi station compared ammonium phosphate sulfate, ammoniated ordinary superphosphate and nitric phosphate in recent field experiments on wheat and corn. These experimental fertilizers, which were provided by the Tennessee Valley Authority, varied in the percentage of citrate soluble phosphate. Since new fertilizer materials must be evaluated under diverse climatic and soil conditions to establish their worth, similar experiments are being conducted in other states.

The production of dicalcium phosphate by direct acidulation of phosphate rock and of a phosphorus-nitrogen compound of complex structure is under study at the Kansas station.

The State stations also are investigating the efficiencies of various liming materials, properties of liming materials significant in neutralizing soil acidity, the value of coarse fractions of agricultural limestone under different cropping systems and nitrogen treatments, new and improved micronutrient materials, mixed fertilizers of differing rates of solution and particle size, use of coatings on fertilizer granules to control rate of solution, and better sampling procedures and methods of analysis for use in fertilizer quality control.

The total State research effort on fertilizer technology investigations is 8.1 professional man-years.

PROGRESS -- USDA AND COOPERATIVE PROGRAMS

A. Materials Development and Refinement

Some commercial mixed fertilizers carry water-insoluble nitrogen in undefined ureaform types either admixed or generated in situ by the proportioned addition of a commercial urea-formaldehyde solution to urea-containing mixed fertilizer. Work on the suitability of the nitrogen materials for fertilizer use was continued with further measurements of biological nitrification characteristics of experimental and commercial fertilizers. Included in the tests were 24 such materials that ranged in grade from 10-3-3 to 20-10-5 and contained 31 to 77 percent of the nitrogen in water-insoluble forms. The quality of the water-insoluble nitrogen in these materials, as gaged by both solubility and nitrification indexes, was found to vary markedly, and the variation to be related to the acidity of the fertilizer. Process conditions, notably temperature in the batch, in factory operation also affected the character of the nitrogen in the fertilizer. In general, the fertilizers with pH above 5 showed satisfactory quality, whereas those with pH below 5 showed poor quality. Low pH had an adverse effect on both the nitrogen solubility and the nitrification expected from a given solubility. These observations point the way to means for improving the level of nitrogen quality in this type of mixed fertilizer. (SWC 13-aC8)

Materials studied the past year included four commercial aldehyde-urea condensation products intended for fertilizer use that had not been previously tested. Orgurea, claimed to be a medium quality ureaform by a producer in Connecticut, had a high activity index, but showed poor nitrification. Crotonaldehyde urea (Floranid) from Germany showed about one-half the nitrification normally observed with ureaform. Azorgan, a ureaform from France, showed very satisfactory activity and nitrification indexes with somewhat more rapid initial nitrification than that exhibited by similar materials made in USA. Results obtained on a urea-formaldehyde fertilizer marketed in the United Kingdom suggest that it is a plastic waste with nitrification character approaching low-grade ureaform, though superior to domestic urea-formaldehyde resin waste, such as button scrap and flash scrap. (SWC 13-aC8)

The preparation of slowly soluble nitrogen fertilizers from urea-formaldehyde resin byproducts of the plastic industry was explored fairly extensively. A substantial, though undetermined, quantity of such material now goes to waste in the industry. Urea-formaldehyde and melamine-formaldehyde waste molding powders were heat treated (80-120° C.) with and without urea additions, in order to determine the effect of heat on the conversion of water-soluble nitrogen to water-insoluble forms. The indicated optimal heating period is 60 to 90 minutes. Heat alone increased the conversion and also the activity index of both types of material and the addition of urea gave further substantial increases, especially in the case of melamine powders. Both materials exhibited activity index maxima, with values in the desirable range for fertilizers, at temperatures of about 80° and 95°, respectively, where conversions of water-soluble nitrogen were about 90 and 50 percent, respectively. (SWC 13-aC8)

These studies establish the feasibility of producing slowly soluble fertilizer from waste molding powders by moderate heat treatments. Nitrification tests in progress will provide information on their likely performance in the soil. Parallel experiments with urea-formaldehyde button scrap showed that the fertilizer quality of the nitrogen in such cured resins could not be improved by this heat treatment. (SWC 13-aC8)

Early in 1962, a domestic concern announced the production of a 12-9-6 fertilizer containing about 40 percent of water-dispersible humic and fulvic acids derived from leonardite mined near Glenrock, Wyoming. Leonardite is partially oxidized lignite and consists mainly of calcium and iron salts of humic and other organic acids. The nitrogen claimed in the commercial product is divided among ammonia, urea and humic forms--5, 6, and 1 percent, respectively. Nitrification was found to occur nearly as rapidly as with ammonium sulfate, but to a slightly lesser percentage of the total nitrogen. Laboratory examination of the reactions of the material indicates that the soluble ammonium humate will tend to change to calcium humate in soil media. (SWC 13-aC8)

Transformation of fertilizer nitrogen in soil environments can be retarded by solubility adjustment, as in the case of ureaform types of carriers, by increasing the particle size of the fertilizer, by interposition of reaction barriers, as in the case of water resistant coatings, and by the incorporation of a chemical that inhibits nitrification. The picoline, 2-chloro-6 (trichloromethyl) pyridine, is being marketed in the West as a nitrification inhibitor. A 2-year old sample of inhibitor-treated (1.6 percent) ammonium sulfate did not behave as expected. This observation supports the suspicion that the volatility of this chemical is too high to permit extended storage of the treated fertilizer without serious loss of inhibiting effect. The experiment is being repeated. Potassium azide is also toxic to nitrifying bacteria. In nitrification tests, 175 parts of KN_3 per million of soil were found to inhibit nitrification of ammonium

sulfate completely over the entire 15 weeks of the test; 17 ppm. prevented nitrification during the first 3 week; and 1.7 ppm. had no noticeable effect. Similar results were obtained with sodium azide. (SWC 13-aC8)

Work on the analytical separation of nitrogen components of fertilizer by ion exchange techniques was continued in 1963. The objective was the isolation of soluble ammonic, nitric, and amidic nitrogen in three solutions for separate determinations of the forms. The principal problem is the establishment of conditions most favorable to recovery of the amidic form. Investigation of the influence of acidity of the test solution on recoveries showed that, whereas the acidity of the solution (pH of 2.0 to 8.0) has little effect on recovery of ammonic and nitric forms, satisfactory recovery of urea nitrogen was obtained only from solutions at a pH of 4.0 to 4.5. The experimental procedure, modified to conform with this pH finding, was applied to synthetic test mixtures (corresponding to 1:1:1, 1:2:2, 1:3:1, 1:4:4, 2:1:1 and 3:2:2 standard commercial grades) of pure salts in solutions of known nitrogen contents. The results obtained on these solutions by the ion-exchange procedure compare very favorably with those obtained by standard procedures. Results found by this procedure for ammonic nitrogen were very close to the amounts present, whereas results on urea-containing fertilizers by standard procedures tend to run high because of hydrolysis of the unseparated urea during analytical operations. The high result for ammonic nitrogen causes a low figure for nitric nitrogen, which in the standard procedure is determined by difference. Thus, the ion-exchange procedure should give the more nearly correct figure for this form of nitrogen, and the results of these tests confirmed this expectation. The case for urea nitrogen is nearly as secure as for the other two forms, although results by the ion-exchange procedure are slightly on the low side in comparison to values obtained by standard procedures. The ion-exchange procedure is now ready for application to commercial fertilizers, which carry many and varied substances (possible trouble makers) not contained in the pure materials thus far used. This phase of the study is underway. (SWC 13-aC9)

Work on the physical characterization of phosphate fertilizer materials was continued with chief emphasis on the effects of calcination on phosphate rock character and less attention than formerly to characterization of phosphate deposits. Response to calcination was found to differ markedly among rock varieties. With increasing temperature, the Morocco rock exhibited a rather abrupt collapse of the internal structure of the particles between 500° and 700° C., whereas the Utah rock was much less changed. Phosphorus solubility decreased in the case of the Morocco rock, but increased to a maximum at 850° in the other variety. Changes occurring in both rocks with increase in retention time were pronounced, but slow so that close control of heating time is not necessary for reproducible results. The reactivity of both varieties was decreased by calcination. (SWC 13-aC11)

Examination of five commercial calcined rocks indicate that the commercial processes operate under conditions that correspond to the threshold of

structural collapse. Thus, it appears that maximal benefits of calcination are being routinely realized. A similar study of Florida land pebble phosphate is in progress. (SWC 13-aC11)

Difference between the reactivities of commercial phosphate rocks have been long recognized by superphosphate manufacturers. A few years ago, this Laboratory developed a scale of reactivity to serve as a means for classifying phosphate rock from different sources. This scale was defined in terms of available specimens of rock from several fields. Although these specimens represent points on the reactivity scale, they do not necessarily typify specific varieties of rock, because rock from the same field may show considerable variability. The type specimen of Florida land pebble was found to have an intermediate reactivity, and since this variety supplies 75 percent of the phosphorus in domestic rock sold or used by producers, a survey was undertaken to determine the range in reactivity presented by Florida land pebble. The survey, nearly complete several years ago, had to be laid aside until a suitable specimen of one recognized type of Florida land pebble (not now mined) could be obtained. A specimen has been procured, and the results of the survey have been reported for publication in 1964. Differences found between the selected specimens of land pebble are much smaller than the varietal differences noted in the development of the reactivity scale. The rock (several years old) used in the definition of the reactivity scale is somewhat more reactive than rock mined in recent years, but not sufficiently so as to make it untypical of the rock variety. (SWC 13-aC11)

Information on the reactivity of new and old phosphate deposits in different parts of the world was supplemented with measurements on rocks from Beaufort County, North Carolina; Phalaborwa, South Africa; Kola Peninsula, U. S. S. R.; and Senegal, Africa. The rock from the first-named location contained 31 percent of phosphoric oxide and showed high reactivity, ranking with North African rocks; those from the second two (39 and 40 percent P_2O_5, respectively) showed low reactivities in the range expected for compact apatites; and that from the last, a calcium aluminum phosphate (30 percent P_2O_5) fell even below the apatites. (SWC 13-aC11)

The greenhouse study mentioned in the 1962 report, to test the value of chromium-bearing slag as a soil amendment was continued through three cuttings of alfalfa. The slag was found to be essentially effective as limestone in correcting soil acidity and promoting yield. The determined calcium carbonate equivalent of the test sample was 118. Little, if any, chromium from the slag was taken up by corn or by alfalfa. (SWC 13-aC14)

The development of rapid photometric methods for determining phosphorus, manganese, iron, aluminum, and titanium in liming materials was continued during 1963. During the year, known procedures were selected with a view toward analyzing for all five of these elements in aliquots of the filtrate from the silica determination, and the chosen procedures, adapted as necessary to this application, were subjected to ruggedness tests on likely

small variations in reagent concentration, order of addition, duration of digestion and rate of cooling, among other things. Differences associated with arbitrary variations in conditions specified in the modified procedures were in no case statistically significant. The procedures utilize the molybdenum blue reaction for phosphorus, the permanganate color for manganese, 2,4,6-tripyridel-s-triazine for iron, Aluminon for aluminum, and Tiron for titanium. (SWC 13-17(aC17))

Sooner or later, all nutrient carriers are wanted in mixed fertilizers to a greater or less extent which poses a question as to the stability of the carrier in the fertilizer. Looking to this need, a study was begun on the persistence of glass and other micronutrient carriers in fertilizer mixtures. One technically convenient place to introduce them is in superphosphate manufacture. Since boron does not form insoluble compounds with the dominant constituents of superphosphate, boron release from boron-containing glass provides a yardstick for measuring the extent of glass decomposition. Exploratory experiments, in which glass was added (a) in the acidulation step, (b) to cured superphosphate, and (c) to ammoniated superphosphate show that as much as 70 percent of the glass may be decomposed in the acidulation step, 10 to 40 percent in moist superphosphate during 6-weeks of storage, and only 1 to 8 percent in ammoniated superphosphate under the same storage. (SWC 13-aC15)

B. Mixed-Fertilizer Investigations

Preparation of radioactive test fertilizers and other materials for experimentation by persons outside of the U. S. Fertilizer Laboratory was continued in response to demand. During the calendar year 1963, 5.8 curies of phosphorus^{32} was received and processed into 22 kinds of fertilizer that contained 41 pounds of phosphoric oxide. These materials were consigned in 33 shipments to 6 cooperators in the United States, 5 in Canada, and 11 in Europe, Asia, and elsewhere. (SWC 13-5(aC5)(Rev.))

A 12-pound lot of glass beads was labeled with gold^{198} for use in fallout tests by the Division's U. S. Soils Laboratory. (SWC 13-5(aC5)(Rev.))

Several lots of special fertilizers (nonradioactive) for experimental use included: three 1,000-pound lots, formulated to have approximately the same N-P-K-Ca-Mg-S ratios and 50 pounds of nitrogen each; five 100-pound lots, including 4 lots of 5-10-5 tobacco fertilizer and an 8-0-24 fertilizer, each containing substantial quantities of potassium nitrate; and eleven 10-pound lots of triple superphosphate containing 10 percent of elemental sulfur for vegetation tests. (SWC 13-5(aC5)(Rev.))

Low-nitrogen grades of mixed fertilizer are difficult to granulate by conventional methods because of the high moisture requirement for granulation and insufficient heat of reaction to raise the batch temperature to a suitable level. In response to inquiries from fertilizer producers, a

series of granulation tests were made on 5-pound batches of a 3-9-9 commercial fertilizer, in which live steam was injected beneath the surface of the rolling fertilizer bed. Good yields (60-70 percent) of on-size product were obtained, the granules were hard enough to withstand normal handling and storage, and the unscreened granulate showed no tendency to cake during drying in air. Plant-scale tests in a fertilizer plant confirmed these bench-scale results and thereupon, the company decided to install steam facilities. (SWC 13-5(aC5)(Rev.))

Work on the effect of physical character of nutrient materials on the granulation of fertilizer mixtures was continued with main attention to the effects of particle size of the mixture as a whole. Results of previous studies indicate that the particle size of the dry mixture before granulation is suitably characterized by its average particle size and the ratio of the diameter of the largest to that of the smallest particle, both of which are susceptible to independent variation and are determinable from sieve analyses of the ingredients. The average particle size of experimental mixtures used in studies on ingredients ranged from 0.16 to 0.52 millimeter, whereas, the size ratio was in all cases 8:1. The results show that a low average size favors granule-to-granule nutrient uniformity, but at the same time, it reduces granulation efficiency. Hence, a compromise between these two effects appears to be the only choice in plant operation. Excellent processability, as regards yield of on-size product and insensitivity to moderate moisture variation in the feed material appears to be a characteristic feature of size distributions that are skewed to the coarse side. Previous experiments do not show the effect of changing the size ratio, because all test mixtures presented the same ratio. However, exploratory tests indicate that mixtures with size ratios less than 8:1 granulate less efficiently than those with a ratio of 8:1 or higher. An investigation of this relationship is in progress. (SWC 13-aC6)

The study on granulation of fertilizers by the slurry process was continued. It was found that the phosphate constituent tends to settle out unless the slurry is agitated vigorously or a suspending agent is used. (SWC 13-aC6)

C. Standardization of Specifications and Test Procedures for Marketed Fertilizers

Work concerned with the improvement of methods of sampling and analysis of fertilizers, liming materials, and other soil amendments and with the promotion of uniformity in trade specifications was continued in cooperation with the Association of Official Agricultural Chemists, Association of American Fertilizer Control Officials, American Society for Testing and Materials and other private associations, as well as with Federal and state government agencies. (SWC 13-4(aC4)(Rev.))

Developments affecting methods for phosphorus include: Adoption of final action by the Association of Official Agricultural Chemists of the quinoline molybdate procedure, which was noted in the 1962 report as having first-action status; completion of a collaborative study on a simplification of the forementioned procedure with the use of the quimociac reagent and adoption of first action by the Association; repeal of first-action status of volumetric quinoline molybdate procedure; adoption of final action of method for preparing sample solution used in direct determination of available phosphorus; deletion of old gravimetric magnesium ammonium phosphate procedure from the next edition of Official Methods of Analysis (though it retains official status); and first-action repeal of the long used volumetric ammonium molybdate procedure, with the urgent provision that the Associate Referee make further effort to overcome its positive bias. Envisioned work in 1964 will be concerned with this charge. In a 16-collaborator study underway, which includes 14 state and 14 industry laboratories, Tennessee Valley Authority and USDA, two proposed modified procedures will be compared with the official quinoline molybdate procedure on 10 fertilizers. (SWC 13-4(aC4)(Rev.))

Results obtained with the automatic analyzer during the past year show that it is sufficiently accurate for routine determination of phosphorus in fertilizers. The interest of people in industry continues. Since there is still room for improvement of the precision and accuracy of the instrument, development work will be continued. (SWC 13-4(aC4)(Rev.))

Analysis of phosphate fertilizers for calcium and magnesium has long been a concern of the Laboratory, though little time has been devoted to method improvement in recent years. Three noteworthy features touched upon the past year are the use of magnesium iodate tetrahydrate as a primary standard for magnesium and two new indicators--hydroxy napthol blue for calcium and o,o'-dihydroxyazobenzene for magnesium. (SWC 13-4(aC4)(Rev.))

The study of methods for determining water in fertilizers was continued with emphasis on the development of a vacuum-oven procedure and a search for a method for the determination of water directly instead of by loss in sample weight. Systematic ruggedness tests on a tentative vacuum-oven procedure showed that oven temperature is the only factor requiring special precaution. Accordingly, a suitable safeguard was incorporated in the procedure, which was then made the subject of a collaborative study to be reported in 1964. A collaborative study on the two current official methods for water, conducted in 1963, confirmed their suitability for present-day fertilizers. Attempts to utilize the Karl Fischer reagent for the direct determination of water were continued. It was found that free water can be determined satisfactorily in fertilizers generally by extracting the sample with p-dioxane and titrating the extract with the Fischer reagent. Analysis for total water requires contact between the reagent and the sample, in which case, the Fischer reagent, as used thus far, works very well on phosphate

rock, diammonium phosphate and urea, but not on superphosphate, ammonium sulfate and most mixed fertilizers. Further attempts to develop this application are anticipated. (SWC 13-4(aC4)(Rev.))

A set of rapid procedures for determining phosphorus, manganese, iron, aluminum and titanium in liming materials is the subject of a collaborative study to be reported in 1964. No experimental work was conducted on methods for quality evaluation of liming materials. The ASTM was actively concerned with specifications for agricultural liming materials, including ratings on the basis of calcium carbonate equivalents, definition and determination of this characteristic, and fineness standards. (SWC 13-4(aC4)(Rev.))

The Committee on Fertilizer Guarantees and Tolerances, Association of American Fertilizer Control Officials, recognizing the need for reliable and up-to-date data as a guideline for the establishment of equable tolerances for use in the enforcement of state fertilizer laws, undertook early in 1963 a collaborative study (in cooperation with the National Plant Food Institute) to determine the capabilities of the analytical laboratories in obtaining unbiased results on unground samples, such as are submitted by fertilizer inspectors. Collaborators were composed of 12 state and 12 industry laboratories. Four 6-pound samples (poor mixes of accurately weighed portions of ingredients) followed by 4 like samples a month later were to be handled as routine fertilizers in a manner that would preclude their recognition as "special" by either the one who prepared the analytical sample or the analyst. The statistical work was to be done by Dr. S. R. Miles, Purdue University. Preparation and shipment of the samples was done at the U. S. Fertilizer Laboratory. The samples were shipped in June 1963, and a report of the findings is expected in August 1964. Duplicate sets of the materials were prepared and held to be ground and homogenized later on for use in the National Plant Food Institute's monthly Magruder Check samples series for 1964. This series of samples, started many years ago and still highly prized in industry and other laboratories, is an aid to maintaining agreement between results obtained in different parts of the country. Some 175 laboratories participate. (SWC 13-5(aC5)(Rev.))

D. Agricultural Chemical Additives

The project on fertilizer as a vehicle for soil application of growth regulators was inactive again this year. Nevertheless, work on this use of other agricultural chemicals was carried out and reported with the nitrification studies. Recently, cooperative work with nematocides was begun. In a revision of this project, the scope is broadened to include any agricultural chemical proposed as an additive to fertilizer. (SWC 13-aC7(Rev.))

E. Consumption Trends and Use Patterns

The regular annual survey of consumption of commercial fertilizer in the United States was completed for the year ended June 30, 1962. Consumption during this period, in millions of tons with percentage gain over 1960-61 given in parentheses, was: All commercial fertilizers, 26.6 (4.0); mixed fertilizers, 16.2 (3.0); primary-nutrient fertilizers other than mixed fertilizers, 9.1 (5.3), most of the increase being registered by nitrogen fertilizers; and secondary and micronutrient materials 1.3 (9.7). Consumption of nitrogen, phosphorus, and potassium was 11.2, 6.1, and 4.7 percent, respectively, more than in 1960-61. The average percentage nutrient contents of mixed fertilizers were: N, 7.08; available P_2O_5, 13.70; K_2O, 12.17--in comparison with 6.81, 13.15, and 11.97 for the preceding year. (SWC 13-aC1)

Among noteworthy trends in fertilizer consumption during the past two decades is its westward movement. Thus, the share of states west of the Mississippi River in the nation's consumption increased from 17 percent in 1945 to 38 percent in 1963. In the same period, the average nutrient content of mixed fertilizers in continental United States increased from 21.51 to 32.91 percent. Nitrogen, which ranked third in nutrient consumption in 1945, is now in first place. The bulk of the nitrogen used for direct application is now in the forms of anhydrous ammonia and nitrogen solutions. (SWC 13-aC1)

The annual preliminary estimate of consumption of commercial fertilizers was nearly completed for the year ended June 30, 1963. The figures show that the tonnage of primary-nutrient fertilizers increased 8.5 percent over the preceding year. Increases in nutrient consumption were as follows: Nitrogen 1.58, available phosphorus 10.2, and potassium 11.7 percent, respectively. The nutrient content of mixed fertilizers registered a further increase, as it has regularly for many years. (SWC 13-aC1)

Collection of information on international developments concerned with fertilizers was continued, and the items were compiled in special reports. Information on fertilizers was supplied to the Agency for International Development, the Organization for European Cooperation, Food and Agricultural Organization of the United Nations, 30 foreign visitors and 16 domestic companies interested in business expansion abroad. (SWC 13-aC3)

At the request of the Agency for International Development in the spring 1963 a study was undertaken to compile fragmentary data on plant nutrient consumption in the less developed countries with special emphasis on Latin America. FAO reports served as a starting point; other data had to be obtained from sundry sources. The findings were summarized in a paper presented to the FCAFE Fertilizer Conference held in Bombay, India, November 18 to December 2, 1963. Projection of consumption in the less developed areas from 1960 at their respective current rates of increase indicated that

fertilizer requirements for the 1980 nutritional goals will be reached by Latin America in 1977, by Asia in 1984, and by Africa in 1990. Plans for the future provide for extensive increase in nitrogen production in all three areas. Future developments in phosphate production center in Africa, where more than half of the known phosphate reserves lie, whereas those in potassium production will be in Asia, particularly in Israel and Jordan. (SWC 13-aC3)

PUBLICATIONS -- USDA AND COOPERATIVE PROGRAMS

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Clark, K. G. 1963. Urea-form is overcoming price barrier. Farm Chem. 126(6): 44, 68.

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Standardization of Specifications and Test Procedures for Marketed Fertilizers

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Consumption Trends and Use Patterns

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Schmidt, Gordon W., and Scholl, Walter. 1963. Trends in fertilizer consumption. Farm. Chem. 126(12): 34.

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Scholl, Walter, Schmidt, G. W., Wilker, C. A., and Toland, H. P. 1963. Consumption of commercial fertilizers and primary plant nutrients in the United States year ended June 30, 1962. ARS 41-19-6; Com. Fert. Yearbook 107(6A): 23-28; Com. Fert. & Plant Food Ind. 107(6): 23-38; Croplife: 76, 78, 80, 82, 84, 86.

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 1	Sedimentation processes in relation to watershed development and protection.			
SWC 1-a1	Development and evaluation of means and measures for channel stabilization in the Northeast.	East Aurora, N.Y.	Yes	1-D
SWC 1-b1	Sediment production, yield and delivery ratio in relation to climatic factors and watershed characteristics in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss. Holly Springs,Miss. Cartersville, Ga.	Yes	1-A
SWC 1-b2	Investigations of the nature and processes of reservoir sedimentation in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss.	No	
SWC 1-b3	Mechanics of sediment entrainment, transportation and deposition in natural and artificial channels in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss.	Yes	1-C
SWC 1-b4	Investigations of stream channel morphology in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss. Watkinsville, Ga. Ft. Lauderdale,Fla.	Yes	1-D
SWC 1-b5	Development of structural measures for sediment control and for stream channel stabilization in the Southern Branch and at the U.S. Sedimentation Laboratory.	Oxford, Miss.	No	
SWC 1-c1	Sediment sources, yields and deposition in agricultural watersheds in Corn Belt states.	Coshocton, Ohio	No	
SWC 1-c2	Stream channel stabilization, sediment control works in channels and mechanics of sediment entrainment, transportation and deposition therein, for Corn Belt states.	Columbia, Mo.	Yes	1-A
SWC 1-d1	Rates and processes of reservoir sedimentation and deposition of sediment in channels and valleys of the Northern Plains.	Hastings, Nebr. Lincoln, Nebr. Newell, S. Dak.	Yes	1-B, D
SWC 1-d2	Sediment production, yield, and delivery ratio in relation to climatic, geologic, and watershed characteristics of the Northern Plains.	Hastings, Nebr. Lincoln, Nebr. Rosemont, Nebr. Newell, S. Dak.	Yes	1-A
SWC 1-e1	Sediment production, movement, and deposition in agricultural watersheds in the Southern Great Plains.	Chickasha, Okla. Riesel, Tex. Sonora, Tex.	Yes	1-C, D
SWC 1-e2	Stream channel stabilization and sediment control works in channels in the Southern Great Plains.	Chickasha, Okla. Stillwater, Okla.	Yes	1-D
SWC 1-f1	Sediment movement and deposition on upstream agricultural watersheds of the Pacific Northwest.	Boise, Idaho	No	
SWC 1-g1	Sediment yields of agricultural watersheds in the Southwest.	Tucson, Ariz. Tombstone, Ariz. Safford, Ariz. Albuquerque,N.Mex. Santa Rosa, N.Mex. Moorpark, Calif.	Yes	1-A
SWC 1-g2	Stream channel morphology and channel stability on agricultural watersheds in the Southwest.	Tombstone, Ariz. Moorpark, Calif.	Yes	1-A, D
SWC 1-g3	Nature and processes of reservoir sedimentation in the Southwest.	Tombstone, Ariz. Moorpark, Calif. Santa Rosa, N.Mex.	Yes	1-B

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 2	Hydrology of agricultural watersheds and associated aquifers in relation to treatment for flood prevention and multiple use of water resources.	Beltsville, Md.	Yes	2-G
SWC 2-a1	The relation of rain, snow, and frozen soils to the hydrology of agricultural watersheds in the Northeast.	Danville, Vt. Blacksburg, Va. Beltsville, Md.	Yes	2-A
SWC 2-a2	Water yield in relation to climatic and watershed characteristics of land resource areas in the Northeast.	Danville, Vt. Blacksburg, Va. Beltsville, Md.	Yes	2-D
SWC 2-a3	Storm runoff and floodflows in relation to climatic and watershed characteristics of land resource areas in the Northeast.	Danville, Vt. Blacksburg, Va. Beltsville, Md.	Yes	2-F
SWC 2-aD1	Analytical hydrography in watershed engineering.	Beltsville, Md.	Yes	2-A, B, F
SWC 2-b1	Relation of climatic and watershed factors to runoff rates and volume yields in the Southern Branch.	Ft. Lauderdale, Fla. Oxford, Miss.	Yes	2-B, F
SWC 2-b2	Precipitation characteristics influencing runoff from agricultural watersheds in the Southern Branch.	Ft. Lauderdale, Fla. Oxford, Miss.	No	
SWC 2-b3	Runoff production by unit source area agricultural watersheds in the South.	Oxford, Miss. Watkinsville, Ga.	Yes	2-E
SWC 2-b4	Subsurface and ground water accretion, depletion, movement and contribution to streamflow for agricultural watersheds in the Southern Branch.	Oxford, Miss. Ft. Lauderdale, Fla.	Yes	2-C, D
SWC 2-c1	Precipitation and snowmelt characteristics influencing runoff from agricultural watersheds in Corn Belt states.	Coshocton, Ohio	Yes	2-A
SWC 2-c2	Runoff production by unit source area agricultural watersheds in Corn Belt states.	Coshocton, Ohio	Yes	2-E
SWC 2-c3	Relation of climatic and watershed factors to storm runoff in Corn Belt states.	Coshocton, Ohio Columbia, Mo. Madison, Wisc.	Yes	2-F
SWC 2-c4	Relation of climatic and watershed physiographic and cultural factors to water yield in Corn Belt states.	Coshocton, Ohio Columbia, Mo. Madison, Wisc.	No	
SWC 2-c5	Aquifer and subsurface relationships in the hydrology of upstream agricultural watersheds in Corn Belt states.	Coshocton, Ohio Columbia, Mo. Madison, Wisc. Fennimore, Wisc.	Yes	2-D
*SWC 2-27 (c6)	Soil moisture regimes of agricultural watersheds in Corn Belt states.	Coshocton, Ohio Columbia, Mo. Madison, Wisc.	No	
SWC 2-d1	Water yield as related to integrated climatic and watershed characteristics in the Northern Plains.	Hastings, Nebr. Cottonwood, S. Dak. Newell, S. Dak.	Yes	2-D, E
SWC 2-d2	Storm runoff and floods as related to integrated climatic and watershed characteristics in the Northern Plains.	Hastings, Nebr. Cottonwood, S. Dak.	No	
SWC 2-e1	Precipitation characteristics influencing runoff from agricultural watersheds in the Southern Plains.	Chickasha, Okla. Bushland, Tex. Riesel, Tex. Sonora, Tex.	Yes	2-A

*New Line Project--Approved March 2, 1964

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964 (Continued)

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 2-e2	Runoff production by unit source areas in the Southern Plains.	Stillwater, Okla. Cherokee, Okla. Chickasha, Okla. Riesel, Tex. Sonora, Tex.	No	
SWC 2-e3	Relation of climatic and watershed factors to storm runoff in the Southern Plains.	Chickasha, Okla. Stillwater, Okla. Riesel, Tex. Sonora, Tex.	Yes	2-F
SWC 2-e4	Relation of climatic and watershed physiographic and cultural factors to water yield in the Southern Plains.	Chickasha, Okla. Riesel, Tex. Sonora, Tex.	Yes	2-C, D, E
SWC 2-f1	Aquifer-streamflow interrelationships in upstream agricultural watersheds of the Pacific Northwest.	Boise, Idaho	Yes	2-C
SWC 2-f2	Precipitation characteristics influencing hydrologic performance of agricultural watersheds in the Pacific Northwest.	Boise, Idaho Moscow, Idaho	Yes	2-A
SWC 2-f3	Runoff and sediment movement on unit source watersheds of the Pacific Northwest as influenced by climate, soils, vegetation, and topography.	Boise, Idaho Moscow, Idaho	Yes	2-B
SWC 2-f4	Water accumulation, flood-wave movement and water yield from complex watersheds of the Pacific Northwest.	Moscow, Idaho	Yes	2-E
SWC 2-g1	Precipitation characteristics influencing the hydrology of agricultural watersheds in the Southwest.	Tombstone, Ariz. Safford, Ariz. Albuquerque, N.Mex. Santa Rosa, N.Mex. Lompoc, Calif. Tehachapi, Calif.	Yes	2-A
SWC 2-g2	Relation of integrated climatic, watershed, and cultural factors to storm runoff from agricultural watersheds in the Southwest.	Tombstone, Ariz. Safford, Ariz. Albuquerque, N.Mex. Santa Rosa, N.Mex. Lompoc, Calif. Riverside, Calif. Logan, Utah	Yes	2-B, F
SWC 2-g3	Relation of integrated climatic, watershed, and cultural factors to water yields from agricultural watersheds in the Southwest.	Tombstone, Ariz. Safford, Ariz. Albuquerque, N.Mex. Santa Rosa, N.Mex. Lompoc, Calif.	Yes	2-C, D, E

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 3	Hydraulics of irrigation, drainage and watershed protection and water supply structures, channels, and facilities.			
SWC 3-c1	Hydraulic design of structures for water use and control in the Corn Belt.	Minneapolis, Minn.	Yes	3-A, B
SWC 3-e1	The hydraulics and measurement of channel, floodplain, and overland flow in the Southern Plains.	Stillwater, Okla. Chickasha, Okla. Tombstone, Ariz.	Yes	3-A, C, D
SWC 3-e2	Hydraulic design of structures for water use and control in the Southern Plains.	Stillwater, Okla. Chickasha, Okla.	Yes	3-B
SWC 3-g1	The hydraulics of channel, floodplain and overland flows in the Southwest.	Tombstone, Ariz. Santa Rosa, N. Mex. Logan, Utah	No	

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 4	Conservation of water supplies for agricultural use.			
SWC 4-b1	Development of water supplies for irrigation in the South.	Tifton, Ga.	Yes	4-B-1
SWC 4-c1	Improvement of water supply sources and storage facilities in the Corn Belt.	McCredie, Mo.	Yes	4-B-1
SWC 4-d1	Facilities, methods and design criteria for pumping, conveying, controlling and measuring irrigation water in the Northern Plains.	Fort Collins, Colo. Newell, S. Dak.	Yes	4-B-2, B-3
SWC 4-13(e2)*	Facilities and procedures for conservation management of runoff water from agricultural lands in the Southern Plains.	Hays, Kans. Big Spring, Tex. Bushland, Tex. Weslaco, Tex.	Yes	4-B-3, C
SWC 4-g1	Control of water use by non-beneficial plants and evaporation losses from storage and conveyance structures.	Humboldt River Basin, Nev.	Yes	4-D
SWC 4-g2	Recharge facilities, methods, principles, and design criteria for storing water in underground reservoirs in the Southwest.	Fresno, Calif. Lompoc, Calif.	Yes	4-C
SWC 4-g3	Control of agricultural water supply and conveyance seepage losses in the Southwest.	Fallon, Nev. Reno, Nev. Yerington, Nev. Logan, Utah	Yes	4-A-1, B-1, 2
SWC 4-gG1	Measurement, evaluation, and control of seepage losses.	Tempe, Ariz.	Yes	4-A-1
SWC 4-gG2	Atmospheric and related boundary mechanisms in water vapor losses from plant, soil and water surfaces.	Tempe, Ariz.	Yes	4-A-2, 3
SWC 4-gG3	Measurement, evaluation and control of infiltration to conserve water.	Tempe, Ariz.	Yes	4-B-1
SWC 4-gG4	Physical processes in the soil affecting preventable losses of water by surface evaporation.	Tempe, Ariz.	Yes	4-A-2
SWC 4-gG5	Water measurement and control for water conservation.	Tempe, Ariz.	Yes	4-B-2
A10-SWC-25	Removal of suspended matter and turbidity from water by flocculation with polyelectrolyte coagulants and coagulation aids.	Technion, Israel	No	

*Approved March 18, 1964

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 5	Irrigation principles, requirements, practices, and facilities for efficient use of water on farms.			
SWC 5-a1	Irrigation practices and factors affecting the water requirement of crops in different land resource areas of the Northeast.	New Brunswick, N. J. Blacksburg, Va. Norfolk, Va.	Yes	5-A-2, 3
SWC 5-b1	Irrigation requirements, practices and methods of application for efficient production of crops in the Southeast.	Thorsby, Ala. Ft. Lauderdale, Fla. Tifton, Ga. Watkinsville, Ga. State College, Miss.	Yes	5-A-1, 2, 3
SWC 5-c1	Improvement in performance and design of irrigation systems in the Corn Belt.	Columbia, Mo.	No	
SWC 5-d1	Irrigation practices, requirements and design criteria for efficient use of water and sustained crop production in the Northern Plains.	Fort Collins, Colo. Grand Junction, Colo. Gunnison, Colo. Hayden, Colo. Lincoln, Nebr. North Platte, Nebr. Newell, S. Dak. Laramie, Wyo.	Yes	5-A-1, D-1
SWC 5-5(e1), Rev.*	Irrigation water management for maximum use efficiency in growing crops in the Southern Plains.	Bushland, Tex. Weslaco, Tex.	Yes	5-A-1, B
SWC 5-f1	Irrigation requirements, principles, and practices for efficient use of water in the Pacific Northwest.	Ontario, Ore. Prosser, Wash.	Yes	5-A-2, 3
SWC 5-f2	Surface and sprinkler design and operation principles and facilities for efficient water use in the Pacific Northwest.	Boise, Idaho Twin Falls, Idaho	Yes	5-C, D-2
SWC 5-g1	Basic irrigation principles in the Southwest.	Pomona, Calif. Logan, Utah	Yes	5-B
SWC 5-g2	Irrigation requirements of forage and cultivated crops in the Southwest.	Lompoc, Calif. Pomona, Calif. Riverside, Calif. Reno, Nev. Logan, Utah	Yes	5-A-1,3,D-1
SWC 5-g3	Intake, transmission and storage of water in irrigated lands in the Southwest.	Pomona, Calif.	Yes	5-C
A10-SWC-11	Further studies on the Blaney and Criddle formula U-KF to ascertain consumptive use of water by plants by means of analysis of climatological data.	Rehovoth, Israel	Yes	5-A-1
A10-SWC-19	The effects of considerable reduction in the intensity of sprinkling irrigation for increased yields, decrease in water duty and improved soil conditions.	Jerusalem, Israel	No	
A10-SWC-5	Performance and scientific design of sprinklers used for irrigation.	Haifa, Israel	No	

*Approved May 27, 1964

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 6	Drainage principles, requirements, practices and facilities for protection of crops and soils.			
SWC 6-a1	Development and evaluation of surface and subsurface drainage practices in different land resource areas of the Northeast.	Burlington, Vt. Blacksburg, Va.	Yes	6-A-1, C
SWC 6-b1	Drainage requirements of crops in the South.	Ft. Lauderdale, Fla. Raleigh, N. C.	Yes	6-E-1, 3
SWC 6-b2	Design, installation and maintenance of surface and subsurface drainage systems with or without land forming and conditioning in the South.	Fleming, Ga. Baton Rouge, La. Raleigh, N. C.	Yes	6-A-1, 2, E-2
SWC 6-c1	Improvement and modernization of surface and subsurface drainage practices and facilities in the Corn Belt.	Morris, Minn. Castalia, Ohio Columbus, Ohio Madison, Wisc.	Yes	6-B-1, 2, E-2, 3
SWC 6-d1	Drainage facilities, methods, and design criteria for protection and improvement of agricultural crops and soils in the Northern Plains.	Fort Collins, Colo. Grand Junction, Colo. Grand Forks, N. Dak. Mandan, N. Dak.	Yes	6-D, E-2
SWC 6-12(e3)*	Improved drainage systems design, materials, installation techniques and drainage requirements of crops in the Southern Plains.	Weslaco, Tex.	Yes	6-B-1, 2, D
SWC 6-g1	Basic drainage principles in the Southwest.	Logan, Utah	Yes	6-E-2
SWC 6-g2	Drainage facilities, methods and evaluation for irrigated lands in the Southwest.	Brawley, Calif. Pomona, Calif. Reno, Nev. Logan, Utah	Yes	6-B-1, D
SWC 6-g3	Drainage and aeration requirements of crops on irrigated lands in the Southwest.	Reno, Nev.	No	
SWC 6-gF1	Principles of drainage as related to salt-affected soils of the Southwest.	Riverside, Calif.	Yes	6-D

*Approved June 1, 1964

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 7	Saline, sodic, and related soils problems, and quality of irrigation waters and their relation to plant growth processes.			
SWC 7-a1	Investigation of the effects of using saline and industrial waste waters on yield and quality of plants and on physical and chemical characteristics of soils in the Northeast.	New Brunswick, N. J. Norfolk, Va.	Yes	7-A-1, B-2, E
SWC 7-b1	The effect of brackish water on plants and soil in the South.	Fleming, Ga.	Yes	7-B-2
SWC 7-d1	Improvement and management of saline and sodic soils of the Northern Plains.	Grand Junction, Colo. Huntley, Mont. Grand Forks, N. Dak. Mandan, N. Dak.	Yes	7-A-2, D
SWC 7-e1	Saline and sodic soils and irrigation water quality problems in the Rio Grande River Basin.	Weslaco, Tex.	Yes	7-A-1, 2, 3, B-2, D
SWC 7-f1	Soil and water management practices for the control or alleviation of saline and sodic soil problems in the Pacific Northwest.	Ontario, Ore.	Yes	7-D
SWC 7-g1	Effect of leaching, amendments, water quality and soil and crop management practices on the soluble salt and adsorbed cation status of salt-affected Southwestern soils.	Yuma, Ariz. Brawley, Calif. Fresno, Calif. Pomona, Calif. Reno, Nev.	Yes	7-C, D
SWC 7-gF1	Mechanisms of reactions between dissolved and adsorbed constituents of salt-affected soils.	Riverside, Calif.	Yes	7-A-1
SWC 7-gF2	Structure, organic matter, and microbial relations in salt-affected soils.	Riverside, Calif.	Yes	7-A-2
SWC 7-gF3	Methods for the diagnosis and study of salinity in soils and water.	Riverside, Calif.	Yes	7-A-3
SWC 7-gF4	Soil physical and chemical conditions in relation to plant growth on salt-affected soils.	Riverside, Calif.	Yes	7-B-1
SWC 7-gF5	Tolerance of economic plants to salinity and exchangeable-sodium.	Riverside, Calif.	Yes	7-B-2
SWC 7-gF6	Plant-water relationships under saline, drought, or high exchangeable-sodium conditions.	Riverside, Calif.	Yes	7-B-1
SWC 7-gF7	Effects of salinity and exchangeable-cation status on absorption, distribution, and metabolic effectiveness of ions in plants.	Riverside, Calif.	Yes	7-E
SWC 7-gF8	Effects of plants of specific ions associated with salinity or exchangeable-sodium.	Riverside, Calif.	Yes	7-B-2
SWC 7-gF9	Influence of climatic and edaphic factors on plant response to salinity and exchangeable-sodium.	Riverside, Calif.	No	
SWC 7-gF10	Chemical composition of irrigation waters in relation to their suitability for use.	Riverside, Calif.	Yes	7-C
SWC 7-gF11	Principles of salinity control, including the amelioration of salt-affected soils by leaching and the use of amendments.	Riverside, Calif.	Yes	7-E

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964 (Continued)

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC-AID-0-1-2	The salt tolerance of plants of special importance to AID missions.	Riverside, Calif.	Yes	7-B-2
SWC-AID-0-1-4	Interpretation and adaptation for AID use of techniques for diagnosis and improvement of salt-affected soils.	Riverside, Calif.	Yes	7-E

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 8	Water and wind erosion control principles, practices, systems, and prediction methods for conservation of crop and rangelands.			
SWC 8-a1	Determination and evaluation of factors affecting water runoff and erosion in the different land resource areas of the Northeast as related to soil and water conservation practices.	Orono, Maine Durham, N. H. Ithaca, N. Y. Marcellus, N. Y. Blacksburg, Va.	Yes	8-A-3, B-1
SWC 8-b1	Effects of soil, topography, climate, cropping and management procedures on runoff and erosion, and on the prediction of soil losses in the South.	Athens, Ga. Tifton, Ga. Watkinsville, Ga. Holly Springs, Miss.	Yes	8-A-2, B-2, D-1
SWC 8-b2	Development of supporting practices, systems, techniques and devices for runoff and erosion control in the South.	Watkinsville, Ga.	Yes	8-A-1, D-1
SWC 8-c1	Basic principles and mechanics of rainfall, runoff, soil movement and loss in the Corn Belt.	Urbana, Ill. Lafayette, Ind. Morris, Minn. Brookings, S. Dak.	Yes	8-A-1
SWC 8-c2	Evaluation of climatic, topographic, soil and crop management factors in relation to water management and erosion control in the Corn Belt.	Lafayette, Ind. Ames, Iowa Beaconsfield, Iowa Castana, Iowa Independence, Iowa Morris, Minn. McCredie, Mo. Madison, S. Dak. LaCrosse, Wisc. Madison, Wisc.	Yes	8-A-2, B-1
SWC 8-c3	Development and refinement of methods for predicting field runoff and soil loss.	Lafayette, Ind.	Yes	8-C-1
SWC 8-c4	Development of supporting runoff and erosion control practices and systems in the Corn Belt.	Castana, Iowa Crookston, Minn. McCredie, Mo. LaCrosse, Wisc.	Yes	8-D-1
SWC 8-d1	Water erosion and its control on irrigated and nonirrigated lands in the Northern Plains.	Lincoln, Nebr.	Yes	8-B-1, 3
SWC 8-e1	Wind erosion control in the Southern Plains.	Colby, Kans. Garden City, Kans Hays, Kans. Manhattan, Kans. Alliance, Nebr. University Park, N.Mex. Big Spring, Tex. Bushland, Tex.	Yes	8-A-1, 2, 3 B-2, C-1
SWC 8-10(e2) Rev.*	Mechanics and principles of water erosion and their application for erosion control in the Southern Plains.	Manhattan, Kans. Cherokee, Okla. Chickasha, Okla. Temple, Tex.	Yes	8-A-3, B-1, D-1
SWC 8-f1	Erosion and runoff control practices and systems to conserve soil and water resources in the Pacific Northwest.	St. Anthony, Idaho Pendleton, Ore. Pullman, Wash.	Yes	8-B-1, D-2
SWC 8-f2	Fundamental aspects of water erosion in the Pacific Northwest.	Pullman, Wash.	No	

*Approved April 8, 1964

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 9	Moisture conservation for the efficient and effective use of precipitation on crop and range lands.			
SWC 9-c1	Development of soil management systems for efficient use of soil moisture in the Corn Belt region.	Morris, Minn. Columbia, Mo. Brookings and Madison, S. Dak.	Yes	9-A-2
SWC 9-d1	Improved water conservation and use on non-irrigated lands of the Northern Plains.	Akron, Colo. Fort Collins, Colo. Bozeman, Mont. Huntley, Mont. Sidney, Mont. Lincoln, Nebr. North Platte, Nebr. Mandan, N. Dak. Newell, S. Dak. Laramie, Wyo.	Yes	9-A-2, A-4, A-5, A-6, A-7, B-1, B-2, B-4, C-3, C-4
SWC 9-e1	Conservation and efficient use of precipitation in the Southern Great Plains.	University Park, N.Mex. Weslaco, Tex. Bushland, Tex Big Spring, Tex.	Yes	9-A-1, A-3, A-5, A-6, B-3, C-1, C-2
SWC 9-f1	Moisture conservation principles and practices in the Pacific Northwest.	St. Anthony, Idaho Pendleton, Ore.	No	
SWC 9-g1	Perfecting cropping sequences, land and water management systems, and cultural practices to conserve and efficiently utilize precipitation.	Riverside, Calif.	Yes	9-B-5

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 10	Soil properties, processes, and management in relation to the conservation and efficient use of land and water resources.			
SWC 10-a1	Development of improved soil management and conservation practices on croplands in different land resource areas of the Northeast.	Presque Isle, Maine Orono, Maine Marlboro, N. J. Marcellus, N. Y. Blacksburg, Va.	Yes	10-C-2, C-4, C-5
SWC 10-a2	Development of improved soil management practices for grassland soils in different land resource areas of the Northeast.	University Park, Pa.	Yes	10-A-4
SWC 10-36 (a3) (supercedes 10-aB5)	Fixation of atmospheric nitrogen by rhizobia.	Beltsville, Md.	Yes	10-D-3
SWC 10-aB1	Fixation of ammonium ion in soils and its release to plants.	Beltsville, Md.	Yes	10-A-3
SWC 10-aB2	Biological transformations of nitrogen in soil, including biological interchange in the rhizosphere, nonsymbiotic fixation, gaseous losses, and accumulation of toxic products.	Beltsville, Md.	Yes	10-A-1, A-3
SWC 10-aB3	Humus formation in soils and the interaction of organic compounds with clays.	Beltsville, Md.	Yes	10-D-1, D-2
SWC 10-aB4	Evaluation of soil-pesticide complexes, including their decomposition.	Beltsville, Md.	Yes	10-B-2
SWC 10-aB6	Genetic studies with nitrogen-fixing organisms.	Beltsville, Md.	Yes	10-D-3, D-4
SWC 10-aB7	The relationship between the soil as the source of nutrients and the ion uptake process in the plant.	Beltsville, Md.	Yes	10-A-2, B-1
SWC 10-aB8	Nutrient balance for plant growth as related to soil environment, plant species and variety, and the nature of added nutrient carriers.	Beltsville, Md.	Yes	10-A-4, B-1
SWC 10-aB9	Development of spectrochemical methods and foliar diagnostic procedures for soil and plant investigations.	Beltsville, Md.	No	
SWC 10-37(aB10)	Physical chemistry of potassium availability in soils.	Beltsville, Md.	Yes	10-A-4
SWC 10-b1	The lime requirements of red and yellow podzolic and related soils.	Thorsby, Ala. Watkinsville, Ga. Holly Springs, Miss. Rio Piedras, P. R. Clemson, S. C.	Yes	10-B-1
SWC 10-b2	The fertility requirement of exposed subsoils.	Cartersville, Ga. Rio Piedras, P. R.	No	
SWC 10-b3	Fertilization for efficient crop production under intensive management.	Thorsby, Ala. Fleming, Ga. Watkinsville, Ga. State College, Miss. Rio Piedras, P. R. Florence, S. C.	Yes	10-A-2, A-4
SWC 10-b4	Developing improved cropping systems for soil conservation.	Fleming, Ga. Watkinsville, Ga. Florence, S. C. Rio Piedras, P. R.	Yes	10-C-5

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964 (Continued)

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 10-b5	Crop residue management and tillage practices for soil conservation and efficient production in the South.	Thorsby, Ala. Watkinsville, Ga. State College, Miss. Holly Springs, Miss. Rio Piedras, P. R. Florence, S. C.	Yes	10-C-2
SWC 10-b6	Factors influencing crop rooting development and activity and means of increasing root development in the South.	Auburn, Ala. Thorsby, Ala.	Yes	10-B-1, C-3
SWC 10-b7	Integration of improved practices for soil and water conservation in the South.	Fleming, Ga. Watkinsville, Ga.	No	
SWC 10-c1	Moisture utilization in the Corn Belt as influenced by soil fertility level and management practices.	Madison, S. Dak. Morris, Minn. Columbia, Mo.	Yes	9-C-5
SWC 10-c2	Tillage practices and crop residue management for soil conservation and efficient production in the Corn Belt.	Ames, Iowa Morris, Minn. Madison, S. Dak. Madison, Wisc.	Yes	10-C-1, C-2
SWC 10-c3	Fundamental studies on the mechanism of soil structure formation in the Corn Belt.	St. Paul, Minn.	Yes	10-C-1
SWC 10-d1	Chemical reactions and availability of phosphates in Northern Plains soils as affected by fertilization, soil properties, and management.	Akron, Colo. Huntley, Mont. Grand Junction, Colo. Mandan, N. Dak. Fort Collins, Colo.	Yes	9-A-7, 10-A-4, A-5, A-6
SWC 10-d2	Soil nitrogen transformations in relation to soil nitrogen maintenance and more efficient use of fertilizer nitrogen in the Northern Plains.	Laramie, Wyo. Grand Junction, Colo. Huntley, Mont. Gunnison, Colo. Newell, S. Dak. Mandan, N. Dak. Fort Collins, Colo.	Yes	10-A-1, A-3
SWC 10-d3	Fertilizer requirements and fertility status of Northern Plains soils for more efficient crop and forage production.	Fort Collins, Colo. Newell, S. Dak. Gunnison, Colo. Bozeman, Mont. Huntley, Mont. Grand Junction, Colo. Mandan, N. Dak.	Yes	10-A-4, A-7
SWC 10-d4	Improved soil management practices and systems for better conservation farming in the Northern Plains.	Akron, Colo. Fort Collins, Colo. Grand Junction, Colo. Bozeman, Mont. Sidney, Mont. North Platte, Nebr. Mandan, N. Dak. Newell, S. Dak. Laramie, Wyo.	Yes	10-C-5
SWC 10-d5	Principles and practices of stubble-mulch maintenance for soil and water conservation in the Northern Plains.	Huntley, Mont. Akron, Colo. Bozeman, Mont. Sidney, Mont. Lincoln, Nebr. North Platte, Nebr.	Yes	10-C-4, D-1
SWC 10-d6	Interrelationships of soil and climate as a basis for predicting applicability of research results, soil response to treatment, and crop yields under different levels of management in the Northern Plains.	Fort Collins, Colo. Cottonwood, S. Dak. Laramie, Wyo.	No	

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964 (Continued)

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 10-e1	Interrelationships between soil structure and plant growth.	Woodward, Okla. Big Spring, Tex. Bushland, Tex. Temple-Riesel, Tex.	Yes	10-C-3
SWC 10-e2	Nutritional requirements for cropland and rangeland in the Southern Great Plains.	Cherokee, Okla. Woodward, Okla. Bushland, Tex. Temple-Riesel, Tex. Weslaco, Tex.	Yes	10-A-1, A-4, A-8
SWC 10-f1	Soil management practices for conservation farming in the Pacific Northwest.	Prosser, Wash. Pullman, Wash. Pendleton, Ore.	Yes	10-B-1, C-2, C-4
SWC 10-f2	Chemistry and availability of nutrient elements in soils of the Pacific Northwest.	Prosser, Wash. Prosser, Wash., & Beltsville, Md. Corvallis, Ore. Pendelton, Ore.	Yes	10-A-7
SWC 10-f3	Chemistry and effects of organic matter in soils of the Pacific Northwest.	Corvallis, Ore.	Yes	10-A-3
SWC 10-f4	Microbial equalibria in soils of the Pacific Northwest.	Prosser & northeastern Wash., northern Idaho	Yes	10-D-5
SWC 10-g1	Principles of nutrient uptake and efficient fertilizer use in relation to moisture regime and irrigation practice, soil properties and crop nutrient requirements in the Southwest.	Brawley, Calif. Tucson, Ariz. Logan, Utah	Yes	10-A-1, A-4, C-5
SWC 10-g2	Improvement of soil fertility, crop production and soil and water conservation through the use of fertilizers and soil amendments on rangeland and nonirrigated cropland in the Southwest.	Riverside, Calif.	Yes	10-A-1, A-4
A7-SWC-7	A study of the soil algae of the rice fields and their contribution to the fertility of the soil.	U. of Allahabad, India	Yes	10-D-5
A7-SWC-17	Iron and molybdenum as plant nutrients.	U. of Lucknow, India	Yes	10-A-7
A7-SWC-29	Investigations on soil structure as influenced by organic matter with the help of microscopic and other techniques.	Indian Agricultural Research Institute, New Delhi, India	No	
A10-SWC-8	Mode of occurrence of minor elements in sediments and soils: A fundamental study for the understanding of the behavior and distribution of minor elements in soils.	Hebrew U. of Jerusalem	No	
A10-SWC-12	The determination of available micro-elements in calcareous soils.	Hebrew U., Rehovot, Israel	No	
A10-SWC-15	Micro-heterometric methods for the quick and precise determination of trace elements in agriculture.	Hebrew U. of Jerusalem	No	
E21-SWC 2	Fundamental studies of reactions between mineral and organic components in soil.	College of Agriculture, Wroclaw, Poland	Yes	10-A-3
E21-SWC-3	Studies on the variability and genetics of Rhizobium.	M. Curie-Sklodowska U., Lublin, Poland	No	

Line Project Check List - Reporting Year April 1, 1963 to March 31, 1964 (Continued)

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
E21-SWC-7	Distribution of micronutrient elements among soil minerals.	Institute of Soil Sci. & Plant Cultivation, Pulawy, Poland	Yes	10-A-7
E25-SWC-7	Study of the retention of some substances of insecticidal and weed-controlling potential by the principal specific clay constituents, and relation of that retention to the specific surface area of the clay constituents, moisture, and temperature.	U. Granada, Spain	No	

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 11	Soil, water, and plant relations as they affect use of land and water resources.			
SWC 11-a1	The energy budget at the earth's surface.	Ithaca, N. Y.	Yes	11-B-7
SWC 11-b1	Modification of soil surface structure and crop geometry to beneficially influence climatic conditions in the South.	Auburn, Ala. Thorsby, Ala. Watkinsville, Ga. State College, Miss.	Yes	11-A-3, B-7
SWC 11-b2	Plant factors influencing transpiration in the South.	Watkinsville, Ga. Florence, S. C.	Yes	11-B-4
SWC 11-b3*	Gaseous losses of nitrogen under field conditions in the Southern states.		No	
SWC 11-b4*	Reduction of strontium-90 by crops.		No	
SWC 11-c1	Soil moisture-plant growth relationships.	Urbana, Ill. St. Paul, Minn.	Yes	11-A-1, B-7
SWC 11-c2	Climatic influence on water use and crop performance in the Corn Belt region.	Morris, Minn.	Yes	11-B-7
SWC 11-c3	Soil moisture flow problems and solutions in the Corn Belt region.	Urbana, Ill. Columbus, Ohio	Yes	11-A-1
SWC 11-d1	Principles affecting soil structure stability and its effect on aeration intake, transmission and storage of water on irrigated lands in the Northern Plains.	Fort Collins, Colo. Grand Junction, Colo.	Yes	11-A-1, B-5
SWC 11-e1	Understanding and improving soil-plant-atmospheric relationships for more efficient utilization of water.	Bushland, Tex. Big Spring, Tex. Manhattan, Kans. Temple-Riesel, Tex. University Park, N.Mex. Weslaco, Tex.	Yes	11-A-2, B-1, B-2, B-3, B-4, B-6, C-1, C-2
SWC 11-13 (g1)	Physical processes affecting soil water and their relationship to physiological functioning of plants.	Davis, Calif. Brawley, Calif. Riverside, Calif. Tucson, Ariz.	Yes	11-A-1
SWC 11-gF1	Physical properties and kinetics of change of the physical properties of water in soil-water systems.	Riverside, Calif.	Yes	11-A-1
SWC 11-gG1	Uptake and disposal of water by plants in an arid climate.	Tempe, Ariz.	Yes	11-A-1, B-3, B-4

*Discontinued July 23, 1964

Line Project Check List -- Reporting Year April 1, 1963 to March 31, 1964

Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 12	Nutrition of animals as affected by properties and characteristics of soils and plants.			
SWC 12-aA1	Studies of the effects of soil and geological conditions on the composition of forages and other crops in relation to nutritional troubles in animals.	Ithaca, N. Y.	Yes	12-A-1, A-2, A-3, B-2
SWC 12-aA2	Effect of environment, soil type, and soil management on the nutritive quality of crops as measured by animal growth, health, and reproduction.	Ithaca, N. Y.	Yes	12-A-1, B-5, D-2
SWC 12-aA3(c)	Micronutrient elements of soils and plants in relation to certain endemic nutritional diseases of animals.	Ithaca, N. Y. Corvallis, Ore.	Yes	12-A-1, B-3, B-4, B-5
SWC 12-aA4	The role of mineral elements, enzymes, nucleic acids, and other factors in the biosynthesis of proteins.	Ithaca, N. Y.	Yes	12-C-1
SWC 12-aA5	Chemical reactions of micronutrient cations with clay minerals and plant extracts.	Ithaca, N. Y.	Yes	12-D-1
SWC 12-aA6	Toxicities in food and forage plants with particular reference to nitrates and certain mineral elements.	Ithaca, N. Y.	No	
SWC 12-aA7	Effect of plant nutrients and other mineral elements on the amino acid and protein content of food and forage plants.	Ithaca, N. Y.	Yes	12-C-2
SWC 12-aA8	The role of mineral elements in the formation of the organic matrix of bone.	Ithaca, N. Y.	Yes	12-B-1

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Work & Line Project Number	Work and Line Project Titles	Work Locations During Past Year	Line Project Incl. in Summary of Progress	Line Project Incl. in Area & Sub-Subheading
SWC 13	Fertilizer investigations: Resources, production, and improvement.			
SWC 13-aC1	Consumption of commercial fertilizers in the United States.	Beltsville, Md.	Yes	13-E
SWC 13-aC2	Sources and trends in the production and use of fertilizers and plant nutrients.	Beltsville, Md.	No	
SWC 13-aC3	Fertilizer resources and development in foreign countries.	Beltsville, Md.	Yes	13-E
SWC 13-4(aC4) (Rev.)	Standardization of specifications and test procedures for marketed fertilizer, liming materials, and other soil amendments.	Beltsville, Md.	Yes	13-C
SWC 13-5(aC5)[1/] (Rev.)	Preparation of special fertilizers (including radioactive material) for experimental use.	Beltsville, Md.	Yes	13-B, C
SWC 13-aC6[2/]	Effect of physical properties of nutrient materials on the granulation of fertilizer mixtures.	Beltsville, Md.	Yes	13-B
SWC 13-aC7[3/] (Rev.)	Fertilizer as a vehicle for soil applications of growth regulators, nematocides, nitrification inhibitors, and herbicides and other agricultural chemicals.	Beltsville, Md.	Yes	13-D
SWC 13-aC8	Suitability of nitrogen materials for fertilizer use.	Beltsville, Md.	Yes	13-A
SWC 13-aC9[4/]	Separation of nitrogen components of fertilizers.	Beltsville, Md.	Yes	13-A
SWC 13-aC10[4/]	Inhibitors of urea hydrolysis.	Beltsville, Md.	No	
SWC 13-aC11	Physical characterization of phosphatic fertilizer materials.	Beltsville, Md.	Yes	13-A
SWC 13-aC12[5/]	Nutritive value of water-insoluble phosphates in multinutrient fertilizers.	Beltsville, Md.	No	
SWC 13-13(aC13)[6/]	Chemical composition and physical characteristics of agricultural limestone.	Beltsville, Md.	No	
SWC 13-aC14[7/]	Utilization of flue dust from cement kilns as a liming material and fertilizer.	Beltsville, Md.	Yes	13-A
SWC 13-aC15	Development and evaluation of primary carriers of zinc for use in crop production.	Beltsville, Md.	Yes	13-A
SWC 13-aC16[8/]	Amounts of nitrogen, phosphorus, and potassium applied to economic crops in 1959.	Beltsville, Md.	No	
SWC 13-17(aC17)[9/]	Development of procedures for determining aluminum, iron, phosphorus, manganese, and titanium in agricultural liming materials.	Beltsville, Md.	Yes	13-A

[1/] Revision approved 2-4-64
[2/] Extended to November 1, 1964, 11-25-63
[3/] Revision approved 7-10-64
[4/] Extended to November 1965, 11-25-63
[5/] Extended to December 1964, 1-22-64
[6/] Discontinued, approved 1-17-63
[7/] Extended to January 1966, 2-14-64
[8/] Discontinued, approved 11-25-63
[9/] Approved 4-24-63